Investigation of medication administration error occurrence in residential aged care facilities within a region of New Zealand: A comparative study of paper-based and electronic charting systems

A thesis submitted in partial fulfilment of the requirements for the Degree of Master of Health Sciences in the University of Canterbury

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2019

Abstract

Medication administration error is a concern for residential aged care facilities (RACFs) in New Zealand. With multiple comorbid conditions, longer life expectancies, and susceptibility to disease, chronic conditions are becoming increasingly complicated for health professionals to manage, increasing the potential for medication administration errors to occur. Further to this, the world is on the cusp of having a greater number of older people than ever recorded, and the healthcare workforce is concomitantly ageing. To prepare for the increase in the older population and an ageing workforce, electronic medication management (EMM) solutions are replacing paper-based systems in RACFs to better support health professionals in care of older patients and enable more efficient care for those patients. It is expected that employment of an EMM solution in residential care settings will reduce medication administration errors overall.

The primary purpose of this research was to assess any change in medication administration error (MAE) rate following implementation of a New Zealand-designed commercial EMM system; the secondary analysis compared the error types occurring before and after the system's implementation. The results based on a Gaussian linear regression model suggest that while there is a downward trend in medication administration error occurrence, there is no statistically significant difference in the rate of errors occurring before and after the evaluated system's implementation with a *p*-value of 0.098 and a relative reduction of 19.7%.

When regression analysis was conducted on solely the aged care related MAE rates, the reduction is statistically significant, producing a *p*-value of 0.03 and a relative reduction of 21.2%. As for the MAE counts by error classification using a Mann-Whitney *U* test, there was only one significant result – wrong time errors, in which medications are administered at the incorrect time, reduced from 13 errors before EMM implementation and 2 after, an 84.6% reduction producing a *p*-value of 0.03.

The overall reduction of medication administration errors is promising and merits further research for development in the residential care space as well as extrapolating EMM use in areas of community health care.

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Preamble

Acknowledgements

I would like to express my sincere gratitude to my two wonderful supervisors Dr Arindam Basu and Dr Philip Schluter for their unending support and calm patience throughout the ups and downs of this project. Thank you for the encouragement to soldier on, for reading so many pieces of drafts, and for sharing your boundless expertise. I have learned so much from you both, and words do not express my gratitude.

I would also like to thank Dr Elena Moltchanova for her statistical guidance in understanding how to model count data.

I am very grateful to Andrew for encouraging me, supporting me, boosting my morale, and keeping me going throughout the past year. I could not have done this without you.

I am also grateful to my family, especially Allyson and Chris, for their constant support, reassurance, and guidance throughout this process.

I would also like to thank the anonymous, but no less appreciated, provider of the data used in this study; without your support, there would be no project here today. Thank you for so generously giving your time to answer my many questions.

Dedication

This thesis is dedicated to my father, Robert C. Cauble, without whom I would not be in New Zealand, much less have finished this thesis.

Glossary

Abbreviations

ADE – Adverse drug event

BCMA – Bar code medicine administration

CPOE – Computerised physician order entry

DHB – District Health Board

EHR – Electronic health record

eMAR – Electronic medication administration record

EMM – Electronic medication management

EN – Enrolled nurse

GP – General practitioner (used interchangeably with 'doctor')

HCA – Health care assistant or caregiver

HIT – Health information technology

HQSC – Health Quality and Safety Commission (New Zealand)

HSW – Health support worker

MAE – Medication administration error

MoH – Ministry of Health (New Zealand)

NHI – National Health Index

NZNC – New Zealand Nursing Council

NZQA – New Zealand Qualification Authority

PRN – *Pro re nata* medicines, or as required medicines

RACF – Residential aged care facility

RN – Registered nurse

Definitions

5 Rights of Medication Administration – The five rights of medication administration to facilitate safe medicine administration to patients: Right patient, right medicine, right dose, right route, and right time (Ministry of Health, 2011c). Often included in the five rights are the additional three checks: correct documentation of the administration, correct indication for the medicine, and consideration of the patient's right to refuse the medication(Ministry of

Health, 2011c). Often displayed as the 5 Rs + 3, or the five rights plus three checks (Ministry of Health, 2011c).

Bed capacity – The total number of patients and RACF can care for (Ministry of Health, 2013b).

District nursing – Nursing support taking place in the home or community to enable "people to remain in their home during health challenges that would otherwise require hospitalisation" (Ministry of Health, 2011a).

Dose pack – The containers in which pharmacists dispense a patient's regular medicines (Ministry of Health, 2013a). These containers can be in a variety of forms but, in RACFs, are generally in blister packs (a sealed plastic container) or in plastic sachets (Ministry of Health, 2011c, 2013a).

Dose time – The time at which a medication has been prescribed to be administered.

Medication round (also drug round) – A period of time during which medications are administered in a residential or hospital setting, e.g. Breakfast or Bedtime.

NHI number – A unique identifier assigned to individuals in New Zealand requiring health care.

Non-packed medicines – Medications which are loosely packaged rather than dispensed by dose, such as liquids, inhalers, or topical creams (Ministry of Health, 2011c).

Packed medicines – Medications which are dispensed by dose into a specialised container, usually a plastic sachet or a blister pack (a sealed plastic container); these medicines are often tablets or capsules (Ministry of Health, 2011c, 2013a).

Polypharmacy – The use of multiple medications simultaneously, which increases the risk of drug interactions and iatrogenesis (Frazier, 2005).

Prescriber – Any health professional who can legally prescribe medications to a patient. This includes but is not limited to doctors, general practitioners, nurse practitioners, psychiatrists, ophthamologists, and dentists.

Progress notes – The written commentary of a patient's overall wellbeing (Nursing Council of New Zealand, 2007, 2012a).

Respite (Patient) – In the aged residential care context, respite patients are elderly individuals staying at residential aged care facilities on a temporary or short-term basis, anywhere from a couple of days to a matter of weeks (M. Willoughby, Ibrahim, Ferrah, & Bugeja, 2018).

Usability – The extent to which a product "allows the user to execute his task effectively, efficiently, and with satisfaction in the specified context of use" (Abran, Khelifi, Suryn, & Seffah, 2003).

User – Those who are intended to utilise a product; also referred to as end users (Collins Dictionary (Online), 2019).

1. INTRODUCTION

Caring for the elderly is known to be complicated (Frey, Boyd, Foster, Robinson, & Gott, 2015; Fuller, Guirguis, Sadowski, & Makowsky, 2018). As a result of longer life expectancies, a rise in chronic conditions, and a greater susceptibility to disease compared to their younger counterparts, the population aged 65 years and over often have multiple comorbidities and, in turn, have multiple medications to manage (Frey et al., 2015; Shannon & McKenzie-Green, 2016). Furthermore, prevalence of chronic illness and likelihood of admission to a residential aged care facility rise with age (Denton, 2010; Kruse et al., 2017).

With these complex health needs of the elderly, as much support as possible is necessary for the health professionals charged with their care, especially those with comparatively limited knowledge about the medications they are administering. With the expansion of technology into numerous industries over the last century, investments have been made in developing health information technology (HIT) to improve efficiencies and health outcomes in healthcare systems around the world. HIT can be defined as "the application of information processing involving both computer hardware and software that deals with the storage, retrieval, sharing, and use of health care information, data and knowledge for communication and decision making" (The Office of the National Coordinator for Health Information Technology, 2013). A range of HIT applications have been implemented in health systems across the globe over the last twenty years, from wound imaging to electronic health records. Applications are used by a variety of different users[1], from health professionals involved in the care of patients, to patients themselves (Zadvinskis, Chipps, & Yen, 2013).

The rapid spread of HIT use across the healthcare industry prompted a move toward employing HIT to improve patient outcomes by providing more comprehensive medication administration documentation, forcing compliance both in medication charting and administration, and enabling better communication between health professionals involved in care (Vicente Oliveros et al., 2017).

In New Zealand, this has in turn prompted a focus on developments in HIT, and new developments have been introduced into the burgeoning aged care industry to improve health outcomes in the elderly (Archer, 2015; Fuller et al., 2018). Electronic medication management

[1] End users, used in this paper interchangeably with 'users', refers to those who utilise a product and for whom it has been designed rather than those who design it (Collins Dictionary (Online), 2019).

(EMM) is one such introduced system with the potential to help efficiently and cost-effectively enable a decent standard of care for the older generation (Anonymous, 2011; Qian, Yu, & Hailey, 2015). In the last decade, many countries have implemented EMM systems in hospitals and residential aged care facilities (RACFs) with the aim of facilitating better, more efficient care, especially by improving medication safety (Fuller et al., 2018).

A major component of improving medication safety is reducing the prevalence and severity of medication errors (Metsälä & Vaherkoski, 2014). Medication errors are the most common cause of preventable harm to patients in primary healthcare (Goedecke, Ord, Newbould, Brosch, & Arlett, 2016; World Health Organization, 2016b). While there is no international consensus of the legal definition of medication errors, they can be generally defined as "any preventable event that may cause or lead to inappropriate medication use or patient harm while the medication is in the control of the health care professional, patient, or consumer. Such events may be related to professional practice, health care products, procedures, and systems, including prescribing, order communication, product labelling, packaging, and nomenclature, compounding, dispensing, distribution, administration, education, monitoring, and use" (National Coordinating Council for Medication Error Reporting and Prevention, 2015; World Health Organization, 2016b). While this definition is broad, it accommodates the potential for a medication error to occur at any point in the medication process, beginning with the manufacturing of the medications themselves (World Health Organization, 2016b). Furthermore, this points to the vast range of errors which can occur in medicinal treatments, from medication manufacturing errors down to the medication being inappropriately taken by a patient or consumer, or, indeed, not being taken at all (World Health Organization, 2016b).

The World Health Organization (WHO) notes that there are various ways to classify medication errors (World Health Organization, 2016b). Broadly, medication errors can be classified based on the stage in the treatment process at which they occur: prescribing; transcribing; dispensing; administration; or monitoring (World Health Organization, 2016b). Alternatively, WHO classifies medication errors more specifically, *e.g.* measuring the types of errors within each broader category (World Health Organization, 2016b). In aged residential care, medication errors are typically measured both as a broad category, such as where in the medication process an error occurs, and classified more specifically within each broader category to describe why the error occurred, such as incorrect labelling of a dispensed medicine. To accommodate that medication

errors can occur at any point in the medication process, medication errors in aged residential care can be classified in one of three ways: prescribing errors, or errors occurring when a prescriber initially prescribes a medicine; dispensing errors, or errors occurring when a pharmacist dispenses and packages a medicine; and administration errors, or errors occurring at the point the patient takes the medicine (Goedecke et al., 2016; World Health Organization, 2016b). All have the potential of resulting in harm to the patient (Masotti & Green, 2010; World Health Organization, 2016b).

A variety of different electronic systems have been developed with the aim of improving medication safety in health care, such as electronic prescribing methods and cloud-based patient management systems (Fuller et al., 2018). Within the medication management space, two medication management systems currently exist in New Zealand: the paper-based system and the electronic medication management system. In New Zealand aged residential care, a major development in the last decade has been the EMM system, taking medication management of long-term care facilities' residents from almost entirely paper-based records and putting them into the cloud.

Since 2014, the electronic systems have been implemented across approximately two-thirds of the New Zealand aged care market. It is expected that such systems improve upon their paper-based counterparts by improving documentation, efficiency, and communication and, as a result, reducing medication errors; however, there is currently a lack of quantitative evidence of the New Zealand to validate this presumption (J. Broad et al., 2011; Qian et al., 2015).

1.1. Purpose and Significance of Study

As the elderly population grows and the use of HIT expands, it is crucial to verify expectations of new systems and the benefits they can provide health providers and patients. EMM systems are relatively new to New Zealand aged care, beginning use in 2014 and accelerating in implementation, becoming a prominent HIT system in the aged care sphere. Various forms of EMM are reported to reduce the numbers of medication errors in their respective settings and, by proxy, improve patient safety. Past research in this area has predominantly been conducted outside of New Zealand in acute care settings such as hospitals rather than in residential care, like aged care or long-term residential institutions. There are fundamental differences in these types of care, notwithstanding that acute care often has other HIT systems working in conjunction with an

integrated EMM system rather than a standalone EMM system, which would be more likely in a residential facility (Fuller et al., 2018). Furthermore, much of the research conducted has entailed short-term, in-depth, observational studies rather than examining a longer-term post-intervention period.

This is the first study comparing the medication administration error (MAE) rates and type occurrences in New Zealand RACFs before and after implementation of an EMM system. As EMM systems have now been in use for five years in New Zealand, EMM systems are becoming more and more common and are well established as common practice in various large residential aged care corporations in New Zealand. As a result, there now exist medication administration error data collected for a year or more which can provide a glimpse of the effect of EMM on medication administration errors well after implementation.

This study aimed to examine and quantify any change in MAE rates in New Zealand RACFs before and after implementation of a New Zealand-based EMM system. Specifically, this study looked to utilise retrospective medication error reporting from an RACF organisation to analyse any difference in error rate and types occurring following the intervention's implementation at the organisation in 2017. A quantitative before-and-after research design was used to assess any differences between a minimum 12-month pre-implementation stage and a minimum 12-month of post-implementation stage.

1.2. Statement of Research Question

It is hypothesised that EMM solutions have reduced the rate of medication administration errors as well as the occurrence of some types of medication administration errors in New Zealand residential aged care facilities when compared to results from the pre-implementation, paper-based medication charting system. The objectives are as follows:

1. To examine any overall changes in medication administration error rate before and after implementation of an EMM system at a New Zealand RACF organisation.
2. To identify any reduction in medication administration errors within specific levels of care.
3. To investigate any change in occurrence of types of medication administration errors before and after implementation of an EMM solution.

It cannot be expected that the MAE rate will reduce to zero following EMM implementation; as EMM systems require human input, elimination of human-generated medication administration errors is impossible. Therefore, the rate of human error is assumed to remain unchanged. However, it is possible that EMM may have positive secondary effects on those using it, such as improving legibility, which may reduce the rate of human error as well.

1.3. Overview of the Thesis

This chapter, Chapter One, discusses the rationale and aims of the study.

Chapter Two of the thesis describes the fundamentals of aged care provision in New Zealand and important factors to consider in the development of HIT for this sector of healthcare. Literature and past research relating to EMM both in acute and residential settings are discussed, focussing on established benefits, consequences, and perceptions.

Chapter Three introduces the methods used in this study, including the nature of and challenges in acquiring appropriate data, research design, and ethical considerations.

Chapter Four relays the results of the research by describing the data and reporting on the results of statistical analysis.

Chapter Five discusses the results and limitations of the study in consideration of past research and the potential for EMM use in other areas of the New Zealand health system. Recommendations for further research in the EMM area are also examined.

2. BACKGROUND & REVIEW OF THE LITERATURE

The global population is ageing fast; people are living longer, and with the baby boomer population approaching retirement and old age, the aged care workforce must face the challenge to meet demand for care (Mitchell, 2014). The colloquial 'Silver Tsunami', or the baby boomer cohort steadily ageing past 65 years, is about to become unprecedented in size, following the World Health Organization's (2011) prediction that the world will have two billion people aged over 60 years by the year 2050, tripling from 600 million in 2000 (Delafuente, 2009; Mitchell, 2014; Shannon & McKenzie-Green, 2016; World Health Organization, 2011). Data suggest the population group over 65 years of age, considered to be a vulnerable sector, will continue to expand over the next thirty years (Mitchell, 2014). Allocation of relevant healthcare resources has been historically slim in the aged care sector over the last few decades, leaving health systems the world over potentially ill-prepared for the consequences involved with having an unprecedented number of people requiring care (Mitchell, 2014). The looming approach of the 'Silver Tsunami' and longer life expectancies increasing potential duration of reliance on aged care have resulted in an increased focus on the aged care sector and its workforce; this has in turn prompted a focus on developments in health information technology, such as electronic medication management, and its potential to help efficiently and cost-effectively enable a decent standard of care for the older generation.

2.1. New Zealand's Ageing Population

Unsurprisingly, New Zealand's population is also ageing rapidly (JLL New Zealand, 2018; Statistics New Zealand, 2018b). Statistics New Zealand estimates a rise in the population aged 65 years and over from 723,050 in 2017 (15% of the total population) to 885,700 in 2023 (17% of the estimated total population) to 1,370,200 in 2043 (23% of the estimated total population) (Forbes, Harvey, & Meyer, 2018; JLL New Zealand, 2018; Statistics New Zealand, 2018b). As the elderly population in New Zealand has historically preferred to remain independent and in their own homes and communities as long as possible, New Zealand's government policy has been geared toward that end (Ministry of Health, 2016; Wiles, Leibing, Guberman, Reeve, & Allen, 2011). This is done primarily by providing services supporting elderly people in their homes as well as delaying admissions to residential aged care (Wiles et al., 2011). Despite the New Zealand government's 'Ageing in Place' policy, enabling elderly people to continue living in their own

homes as long as possible, 24-hour care in the form of residential aged care facilities, or RACFs, will be increasingly needed (Fleming, 2010). This is especially the case considering longer life expectancies, with the national life expectancies currently at an average of 83.19 years for women and 79.48 years for men, an increase of 3.52 and 5.07 years respectively over the last twenty years (Fleming, 2010; Statistics New Zealand, 2018a).

Furthermore, as elderly people are remaining in their homes longer prior to entering residential aged care, they tend to present with higher numbers of co-morbidities and more complex care cases than before, rendering them more dependent overall (J. B. Broad, Ashton, Lumley, & Connolly, 2013; Connolly, Broad, Boyd, Kerse, & Gott, 2014; Shannon & McKenzie-Green, 2016). Higher numbers of people requiring aged care combined with more complex healthcare requirements upon aged residential care admission, and then again accompanied by longer life expectancies have made evident in the inevitability of an increase in capacity of aged residential care beds and an increase in workforce and potentially qualification of that workforce (Connolly et al., 2014). In many cases in the last decade, aged residential care in New Zealand is becoming a long-term *de facto* hospice, in which highly dependent elderly people are often residents of RACFs until end of life (Connolly et al., 2014). This was not always the case; palliative care was not often offered in aged care facilities and was generally provided by hospices in the last days of one's life (Connolly et al., 2014). New Zealand, however, has the highest number of reported deaths at 38% in aged residential care among an international study of 45 populations (J. B. Broad, Gott, et al., 2013), increasing the notion that aged residential care is where elderly people go to die (Connolly et al., 2014; Frey, Boyd, Robinson, Foster, & Gott, 2017).

Admission to residential aged care facilities is often treated as a last resort rather than a preemptive action (Cooney, 2012; Jaye et al., 2015). Elderly people are often admitted to residential care following a trauma of some kind, like a fall, and any resultant hospitalisation (Jaye et al., 2015; Ministry of Health, 2018c); events like these can be caused by physical frailty or by underlying issues, such as dementia (Jaye et al., 2015; Ministry of Health, 2018c). Such events, following assessment by a medical professional, can be treated as indicators of an inability to live alone safely (Jaye et al., 2015; Ministry of Health, 2018c). As a result, the transition to residential care is generally not perceived in a positive way and can trigger feelings of loss, grief, and anxiety, especially when confronting the inability to complete intimate tasks alone, such as toileting or showering (Cooney, 2012; Jaye et al., 2015; Lee, Simpson, & Froggatt, 2013).

This is especially pertinent in the population aged 75 and older, as they are more likely to require care, and with Statistics New Zealand estimating a rise in this cohort from 306,730 in 2017 to 393,600 in 2023 and 783,600 in 2043 (a factor of two increase in about 25 years), aged care services must adjust quickly to accommodate the change (JLL New Zealand, 2018). As of September 2018, there were 669 distinct aged care facilities housing 38,798 beds at approximately 87.6% occupancy nationwide (Evans, 2018; Fleming, 2010). It should also be noted that while occupancy is not at 100%, the absolute number of admissions to aged care facilities is stable or rising in New Zealand (Connolly et al., 2014). Even now the workforce and funding are insufficient to meet current demand, much less face the looming increase in patient numbers and their health needs, which are becoming increasingly complex with longer life expectancies, a rise in chronic conditions, and resultantly, multiple comorbidities to manage (Forbes et al., 2018; Frey et al., 2015; JLL New Zealand, 2018; Shannon & McKenzie-Green, 2016). Further to this, people are entering aged care at later stages in illness, requiring higher skill levels to manage; as the number of admissions rises, so does the dependency of those admitted (Connolly et al., 2014; Frey et al., 2015).

2.2. The Ageing Health Care Workforce and the Need for Increased Efficiency

Compounding the problem of an ageing population entering RACF care is the ageing health care workforce itself. As the population ages, becomes more dependent, and requires increasing health care assistance, so does the health care workforce tasked with caring for it. The average age of RACF staff in New Zealand was approximately 46 years in 2015 (Cassie, 2017). August 2018 saw a record 500 registered nurse, or RN, vacancies in New Zealand aged care facilities, roughly 10% of the total positions available at that time (A. Taylor, 2018). With a mean age of 50 years for New Zealand RNs, it is expected that a bulk of RNs in New Zealand will be leaving the industry for retirement or, at minimum, reducing hours worked over the next ten years (Moloney, Gorman, Parsons, & Cheung, 2018). The World Health Organization has predicted that by 2030, the worldwide population will be short 14 million doctors and nurses (World Health Organization, 2016a). With an ageing healthcare workforce beginning to retire concurrently with the rise in healthcare needs for an ageing population, implementation of new efficiencies and retention policies are urgently necessary (K.-E. J. Elliott, Rodwell, & Martin, 2017; Graham & Duffield, 2010; Moloney et al., 2018).

2.3. Residential Aged Care Facilities

New Zealand aged care focusses on enabling elderly people to continue living in their own homes and within their own communities as long as possible through the New Zealand government's 'Ageing in Place' policy (Fleming, 2010; Wiles et al., 2011). This is preferable to many older people who want to remain independent in their own homes as long as they can prior to entering their final stages of life (Wiles et al., 2011). However, as people age, their ability to care for themselves independently diminishes and health deteriorates, often leading to admission to RACFs. RACFs provide institutionalized accommodation for the elderly who require support in some capacity, often health-related (Mulley, Bowman, Boyd, & Stowe, 2014; Shannon & McKenzie-Green, 2016).

Broadly, there are two kinds of RACFs in New Zealand: hospital level care, or high-level care, and rest home care, or low-level care (J. Broad et al., 2011; Burrow, Gilmour, & Cook, 2017; Standards New Zealand, 2013). The key difference between the two is that those in hospital level care, often including dementia care, require 24-hour medical attention, whereas those in rest home care require support, but not 24-hour medical care (J. Broad et al., 2011; Standards New Zealand, 2013). However, it may be that there is overlap between the two care levels; due to high occupancy rates, it is likely that some RACF residents requiring hospital level care are actually being cared for at the rest home level (Burrow et al., 2017). Furthermore, the care level type does not necessarily apply to the entirety of an RACF, but rather it applies to a part of an RACF or even the level of care permitted for a bed (or the individual cared for in that bed), blurring the lines between the two levels of care and rendering the care levels less starkly categorical in nature (Ministry of Health, 2004). There are other levels of residential care that often fall into these categories, despite not necessarily being aged care specifically (New Zealand Government, n.d.). Dementia care, for example, can be found both at the rest home and hospital levels of care, whereas psychogeriatric care is considered hospital level care; psychogeriatric care can include dementia care when the dependency of the individual is considered to be high (Burrow et al., 2017; Technical Advisory Services, (n.d.-b), (n.d.-c)). RACF staff provide medical support in varying forms, including giving prescribed medication to those who are no longer capable of managing it themselves (Mulley et al., 2014; Shannon & McKenzie-Green, 2016). As medication-related activities can take up a large portion of a health professional's time in an RACF, it is crucial that medication management processes adequately support the staff involved as there have been shortcomings

identified in this area (Ahmad Nizaruddin, Omar, Mhd-Ali, & Makmor-Bakry, 2017; Cotter, Donlon, Roche, Byrne, & Fitzpatrick, 2012).

2.4. Medication Administration of Residential Aged Care Facilities

Up to 40-50% of a clinician's time in an RACF can be spent on medication-related activities (Ahmad Nizaruddin et al., 2017; Cotter et al., 2012). However, the levels of medication knowledge vary among those qualified to give medications in RACFs. Currently in New Zealand RACFs, medications can be administered by registered nurses (RNs), enrolled nurses (ENs), and medication-competent health care assistants (HCAs/caregivers), with all members required to undergo an assessment for medication competency on an annual basis (Ministry of Health, 2011). Standards and competencies related to registration as an RN or an EN are set out and regulated by the Nursing Council of New Zealand (Shannon & McKenzie-Green, 2016). RN and EN practice are heavily regulated by multiple bodies in New Zealand; as are all regulated health practitioners in New Zealand, RNs and ENs are bound by the Health Practitioners Competence Assurance Act, intended to ensure the safety of the public by ensuring the competence of New Zealand's clinicians (Ministry of Health, 2017). Regulatory responsibility of RNs and ENs falls predominantly to the Nursing Council of New Zealand (NCNZ) (Shannon & McKenzie-Green, 2016; Vernon, Chiarella, & Papps, 2011). HCAs and their training or education requirements, however, are accountable to their employers (Burrow et al., 2017; Nursing Council of New Zealand, 2012b).

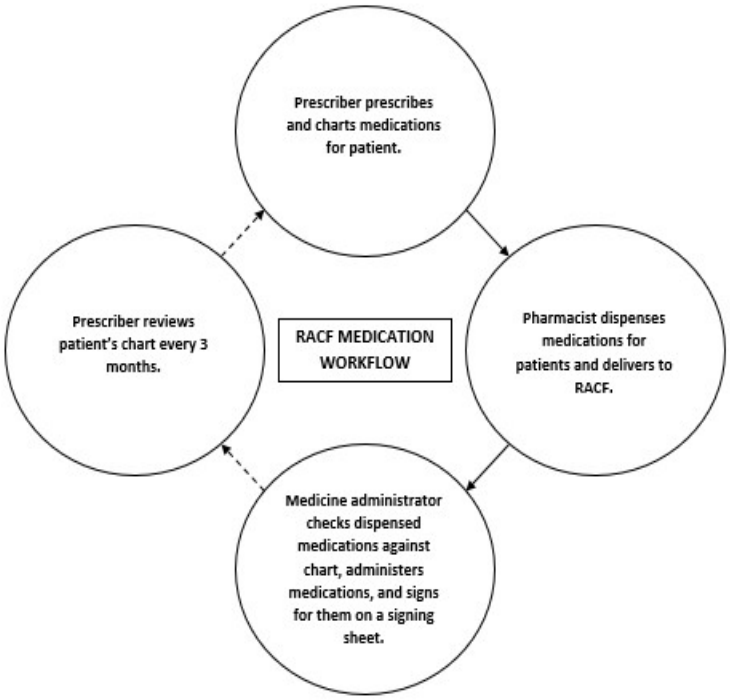

Figure 1: Residential aged care facility medication delivery workflow

2.4.1. Registered Nurses

Registered nurses, or RNs, are considered the chief medical caretakers of RACF residents (Ministry of Health, 2011c). Following a minimum of three years formal full-time education and a comprehensive registration examination, New Zealand RNs are typically the most medically educated, or medication-competent, RACF staff members and are responsible for other staff members administering medications at the RACF (Ministry of Health, 2011c). RNs complete a Bachelor-level degree measured at level 7 on the New Zealand Qualification Authority (NZQA) framework[2] (Shannon & McKenzie-Green, 2016). RNs have the ability to check and administer all prescribed medicines at an RACF as well as monitor the health of RACF residents by conducting nursing assessments (Ministry of Health, 2011c; Nursing Council of New Zealand, 2007); this renders them the main port of call for medication administration at RACFs (Nursing Council of New Zealand, 2007). By law, rest home level RACFs in New Zealand must employ a certain number of RNs proportional to the resident capacity, not including self-managed units (Ministry of Health, 2004). A staff member must be on the premises at all times, and an RN must always be available or on call (Ministry of Health, 2004). Hospital level RACFs, as high-level care facilities, require at least one RN on duty at all times (Ministry of Health, 2004).

Expectations of RNs in RACFs are high. As the RACF staff members with the highest level of medical competency, RNs have more responsibilities compared to their other medicine-competent colleagues. Not only does this include the typical responsibilities of those charged with managing the health of others, such as administering medicines, participating in health reviews and assessments, identifying health risks and risk factors, and maintaining an up-to-date knowledge base related to care of older individuals – RNs are also responsible for RACF residents under the medical care of other RACF staff members who generally are not as medically educated as an RN (Nursing Council of New Zealand, 2007; Shannon & McKenzie-Green, 2016). This means effectively RNs are responsible for all medical decisions made by enrolled nurses or healthcare assistants at RACFs in addition to their own medical decisions. While this makes for a

[2] NZQA qualifications are awarded levels 1-7 based on the knowledge and skills acquired as part of the qualification (New Zealand Qualifications Authority, 2016). As the knowledge and skills increase, so does the numerical value. These are often technical in nature and followed by Bachelor degrees, graduate diplomas, Bachelor degrees with Honours, Postgraduate qualifications, Master degrees, and Doctoral degrees (New Zealand Qualifications Authority, 2016).

high amount of autonomy within the position, it coincides with a great deal of responsibility and accountability (Mulley et al., 2014).

Medication management for RACF residents is one of many responsibilities facilitated by RNs. RNs are also responsible for wound treatment and dressings, physical assessments and general observations of patients, and interRAI assessments[3], made mandatory in 2015 (Burrow et al., 2017; INsite Magazine (Online), 2016; Ministry of Health, 2018a). In addition to the oversight of treatment and direct care of RACF residents, RNs also have numerous administrative and managerial tasks, like rostering of staff, arranging orders from the pharmacy, updating progress notes, referrals to specialists, organizing and attending doctors' rounds[4], and showing potential clients and their family members around (Burrow et al., 2017; Lim, Chiu, Dohrmann, & Tan, 2010). A 2008 study in San Diego, California, USA, found that 31% of RN time in an RACF is dedicated to direct care of patients, and 94.6% of productive RN time spent on general care, including medication administration, reading and writing in charts, washing hands, taking vitals, and other tasks (Dellefield, Harrington, & Kelly, 2012). Other tasks included mobility, nutrition, pain management, elimination, pressure wound treatment and management, documentation, and supervision of and interaction with other staff (Dellefield et al., 2012).

Morale and satisfaction are notably low for RNs in the aged care sector in New Zealand, and, indeed, on a global scale (K.-E. J. Elliott et al., 2017; Walker, 2017). As noted previously, August 2018 saw a record number of RN vacancies in New Zealand aged care facilities, with RNs reputed to be fleeing the aged care sector for the better-paying and better-resourced positions in hospitals and private care (INsite Magazine (Online), 2018; A. Taylor, 2018).

2.4.2. Enrolled Nurses

Enrolled nurses, or ENs, are generally not quite as educated as RNs and must work under the supervision of an RN when working in RACFs (Nursing Council of New Zealand, 2012a; Shannon & McKenzie-Green, 2016). In 2010, EN education was expanded to an 18-month

[3] interRAI, or the International Residential Assessment Instrument, is a suite of clinical assessment tools devised in Canada (Ministry of Health, 2018a; The University of Auckland: Medical and Health Sciences: News (Online), 2018). The Long-Term Care Facility (LTCF) instrument was mandated for use in New Zealand RACFs in July 2015 to aid in ensuring the best care is provided to patients on an ongoing basis in RACFs rather than only based on initial admission (INsite Magazine (Online), 2016; Ministry of Health, 2018a; The University of Auckland: Medical and Health Sciences: News (Online), 2018).

[4] Doctors' rounds refer to onsite visits from the doctor(s) to the RACFs to review patients' charts and treatment plans.

diploma course in New Zealand, gauged at level 5 on the NZQA framework (Reed, 2010; Shannon & McKenzie-Green, 2016). ENs must, like RNs, undergo an assessment at the completion of their studies, and the records of education and scope are regulated by the New Zealand Nursing Council (NZNC) register, like RNs (Nursing Council of New Zealand, 2012a; Reed, 2010). Since the 2010 expansion, ENs are better able to support RNs in the care of patients with higher care needs; furthermore, ENs who qualified after the 2010 expansion are able to coordinate HCAs under the direction of an RN (Nursing Council of New Zealand, 2007, 2011; Shannon & McKenzie-Green, 2016). However, RNs remain accountable for supervisory actions taken by ENs (Nursing Council of New Zealand, 2012b; Shannon & McKenzie-Green, 2016). ENs must work under the direction and delegation of an RN, but as a result of their formal education, they are well-equipped to support RNs in general nursing duties (Nursing Council of New Zealand, 2012a); ENs are trained to contribute to nursing assessments, have an understanding of health interventions, and can help RNs with care plans; the responsibility of care, however, like the supervisory accountability, remains with the supervising RN (Nursing Council of New Zealand, 2012a). ENs can also check and administer oral, topical, rectal, intramuscular, and subcutaneous medicines (Ministry of Health, 2011c).

2.4.3. Healthcare Assistants/Caregivers

Healthcare assistants, or HCAs/caregivers, provide the majority of direct care to RACF residents in New Zealand. Like ENs, HCAs must work under the supervision of an RN, but unlike ENs, HCAs do not appear on the NZNC register, as HCAs are not required to undergo any professional training in order to become an HCA at an RACF. While there are now courses one can take to better prepare for an HCA role in a facility, HCAs generally do not have any qualification above level 4 on the NZQA framework. According to a self-report survey, 82% of HCAs have completed some form of education in the National Certification in Health, Disability, and Aged Support (Ravenswood, Douglas, & Teo, 2014; Shannon & McKenzie-Green, 2016). Smith *et al*. reported that educational intervention for HCAs increases the quality of care given (Smith, Kerse, & Parsons, 2005). According to Grant Thornton NZ Limited, approximately 18,150 unregulated health care employees were working in New Zealand aged residential care (Fleming, 2010). Comparatively, according to the Nursing Council of New Zealand, there were 4469 RNs and 794 ENs working in aged residential care in 2015 (Nursing Council of New Zealand, 2015).

These statistics markedly illustrate that the majority of direct care of RACF residents in New Zealand is performed by unregulated HCAs.

HCA role definitions vary, but HCAs are generally responsible for providing fundamental levels of care to RACF residents, such as personal hygiene, ambulation, repositioning, other physical movement, and assistance with daily activities, like eating (Burrow et al., 2017). In recent years, HCA roles have expanded to include more responsibilities (Burrow et al., 2017); for example, HCAs are now most often the staff at New Zealand RACFs to administer medicines directly to residents as well as provide the more basic care (Burrow et al., 2017). This was not always the case – RNs ordinarily were responsible for administering medicines as well as other patient health care, such as wound treatment (Burrow et al., 2017). However, generally resource-poor environments, like RACFs, need flexibility around responsibilities and unforeseen circumstances to ensure care is given to residents (Burrow et al., 2017; Jansen et al., 2017; Shannon & McKenzie-Green, 2016).

HCAs and their ability to administer medication in New Zealand RACFs are, at present, not regulated by any government body. Despite the absence of a requirement to have any standardised education into the complexities of medications, their interactions, and risks of administration, HCAs are able to check and administer oral, topical, and rectal medicines to RACF residents. Instead of undergoing registration examinations, like RNs and ENs, HCAs are instead assessed directly by an RN within the RACF prior to being permitted to administer medications. Resultantly, standards or policies around determining medication competency for HCAs can vary from RACF organisation to organisation, which can theoretically contribute to a great deal of variation in care among RACFs.

All RACF staff members who administer medications to residents must undergo annual medication competency assessments as per RACF audit requirements (Ministry of Health, 2015; Standards New Zealand, 2008). While RACF audit information is available on the New Zealand Ministry of Health website, documentation pertaining to staff member medication competency is available only at the RACF itself (Ministry of Health, 2015; Standards New Zealand, 2008).

2.5. Medicine Charts & Signing Sheets

Care staff at RACFs, including RNs, ENs, and HCAs, use administration records, or signing sheets, and medicine charts to record medications prescribed for and administered to

patients (Health Quality and Safety Commission, 2012b). Medicine charts are not simply comprised of a list of prescribed medications and instructions on their administration; they also include a number of other components aimed at supporting health professionals in the safe care of the patient, such as allergies, adverse reactions to medicines, and other patient information, especially documentation to correctly identify the patient (Health Quality and Safety Commission, 2012b). RNs, ENs, and HCAs must use the chart and the signing sheet to accommodate the five "Rights" of medication administration, or the "5 Rs + 3":

- Right Patient
- Right Medicine
- Right Dose
- Right Route
- Right Time

RNs, ENs, and HCAs must also complete an additional three checks, or the "+ 3" in the equation: documenting the administration correctly; ensuring the medicine was given for the correct indication; and considering the patient's right to refuse the medication (Ministry of Health, 2011c). Medicine charts are in many ways the point of truth in terms of what is prescribed for an RACF patient, and while preventable adverse drug errors can take place at any point in the medication process, most occur at the prescribing or medicine administration stages (Guo, Iribarren, Kapsandoy, Perri, & Staggers, 2011). As charts are used collaboratively by all health professionals involved in an RACF patient's care, such as prescribers (clinicians with the authority to prescribe medications), RNs, and pharmacists, the charting process can be error-prone (Guo et al., 2011).

Historically, only paper charts and signing sheets have been used for medication administration in both hospital and residential care. New Zealand's 20 District Health Boards (DHBs) each employed their own medication chart format in their hospitals; this caused a number of issues – for example, transfer of medical staff between the DHBs was problematic in that safe prescription or administration of medication required extra training for staff to ensure proper documentation (Health Quality and Safety Commission, 2012b). This resulted in various medication errors, prompting the standardisation of a National Medication Chart in 2011 (Health Quality and Safety Commission, 2012b).

In aged care, the paper chart, dictating the medications prescribed for an RACF patient and the instructions for their administration, is reviewed at least every 90 days. Upon review, the chart is entirely rewritten. Any changes made to the chart between chart reviews must be made on the written chart itself, so any changes made to a currently charted medication is effectively crossed out and rewritten in a new line. In cases of complex care, this means the chart can quickly become very messy (R. A. Elliott, Lee, & Hussainy, 2016). Further, only a prescriber may record the change, involving either a physical visit to the RACF or a series of faxes back and forth between RACF and practice. The chart is used in conjunction with a paper signing sheet, on which the RN, EN, or HCA administering a medication signs that a medication was either administered (or that it was not), and the time the administration took place. Any incidents involving medication administration or an RACF patient's general status is recorded in further detail in the patient's clinical progress notes, the written commentary of the patient's wellbeing (Nursing Council of New Zealand, 2007, 2012a).

RACFs do not currently have standardized medication charts like their acute care peers; as of 2018, the Health Quality and Safety Commission (HQSC) of New Zealand began implementing an electronically generated printed paper chart in an attempt to standardise charts across RACFs and in turn reduce errors, but implementation of this chart is not mandatory (Health Quality and Safety Commission, 2018).

In New Zealand RACFs, medications are usually distributed using a medication trolley containing the medications dose packs[5] for the residents of that wing or location of the RACF. The trolley is wheeled out of the locked treatment room and taken to where the medications are to be administered, whether that be in the RACF's dining room (at lunchtime, for example) or in a resident's room. The care staff member doing the medication round often wears a smock or tabard to indicate to residents and other staff members that he or she is doing the medication round; this is predominantly to avoid distractions which can contribute to errors, as the medication round requires concentration (Dellefield et al., 2012; Scott, Williams, Ingram, & Mackenzie, 2010). The medication administration process in RACFs is further detailed in *Figure 2.*

[5] Dose packs are the containers in which pharmacists dispense a patient's medicines prescribed for a specific time, such as Breakfast (Ministry of Health, 2013a). These containers can be in a variety of forms but, in RACFs, are generally in blister packs, or a sealed plastic container, or in sachets (Ministry of Health, 2013a). Dose packs are labelled with what medicines they contain and how many tablets or capsules of each are within, assisting the dose-checking process for medicine administrators (Ministry of Health, 2013a).

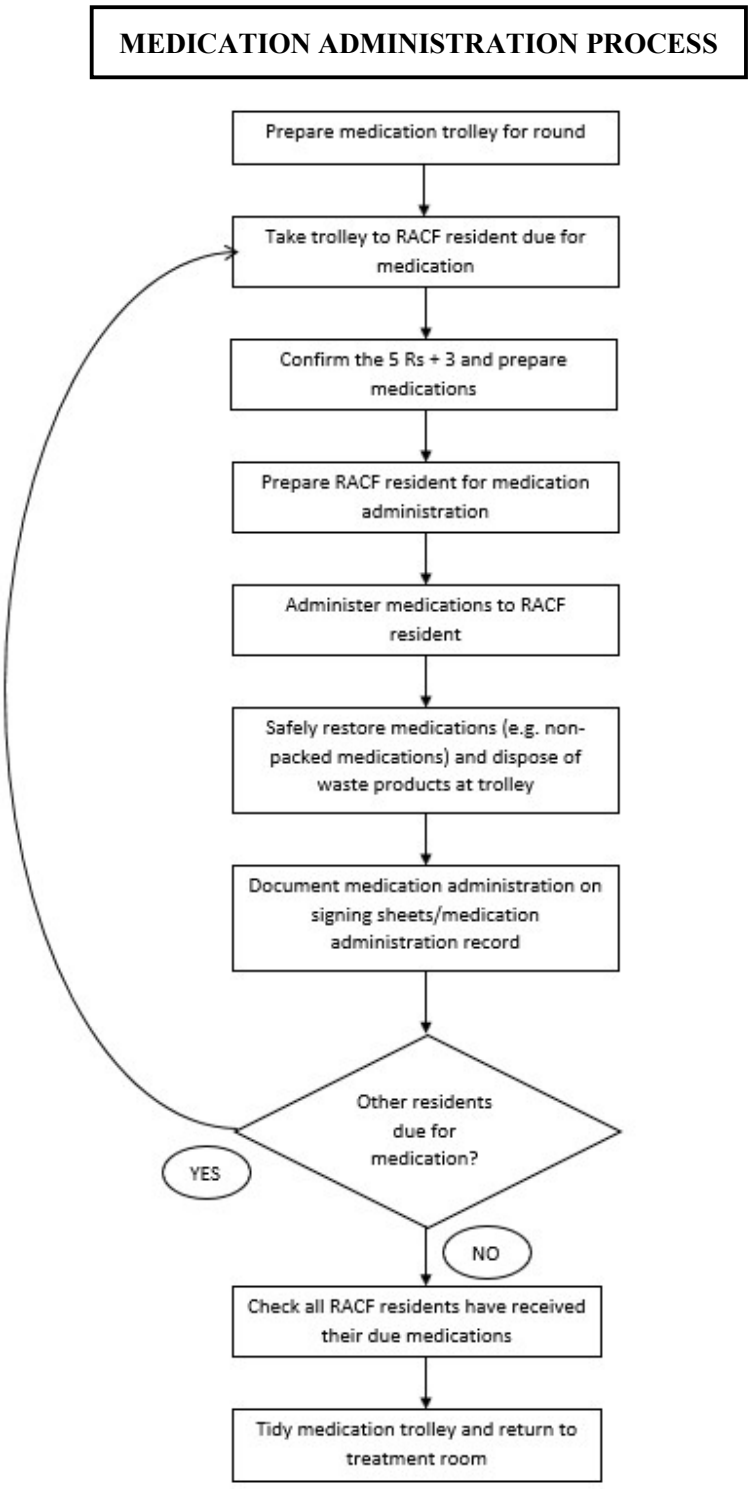

Figure 2: RACF medication administration process

A recent study evaluating the amount of time RNs spend on medication administration in RACFs found medication administration consumes a substantial amount of RN time at between

2.3 and 4.5 hours per medication round, or an average of 37% of the RN's time during a standard 8-hour shift, with patients in the study taking an average nine different medications each during the morning round (Qian, Yu, Hailey, & Wang, 2016). It can therefore be stated that medication administration is a major factor in considering RACF staff workloads as well as procedural or environmental changes in RACFs (Qian et al., 2016).

2.6. Medication Errors

Medication errors, as discussed previously, are any "unintended failure in the drug treatment process that leads to, or has the potential to lead to, harm to the patient"(Goedecke et al., 2016). Medication errors can occur at any time during the medication management process for a patient (Ahmad Nizaruddin et al., 2017; Berdot et al., 2012; Goedecke et al., 2016; National Coordinating Council for Medication Error Reporting and Prevention, 2015; World Health Organization, 2016b). The rate of medication errors varies widely across different studies and different countries, and while it can be generally concluded that only a small percentage of medication errors result in serious harm, the potential undesirable outcomes of a medication error could be dire, especially considering the increasing number of medications prescribed and their possible interactions (Archer, 2015; Fialová & Onder, 2009; Metsälä & Vaherkoski, 2014; World Health Organization, 2016b). The number of possible undesirable outcomes of a medication error is large but the primary ones include adverse drug reactions or events, interactions between drugs administered, and lack of efficacy (Metsälä & Vaherkoski, 2014; World Health Organization, 2016b).

While medication errors are perceived as being physically harmful only to the affected patient(s), they impact the economic and environmental facets of the health system as well (Masotti & Green, 2010; World Health Organization, 2016b). Avoidable admissions to hospital are also costly for health systems (Bhuyan et al., 2015; Brennan & Tomasiuk, 2018; Robb, Loe, Maharaj, Hamblin, & Seddon, 2017; Seibert, Maddox, Flynn, & Williams, 2014; World Health Organization, 2016b). Medication errors are therefore not only a health burden, but an economic one as well (Ramos, Caekelbergh, & Lamotte, 2015; Robb et al., 2017). Ramos *et al*. found that based on an estimated incidence rate of 2.6% of all hospital admissions attributable to medication errors, avoiding these avoidable hospitalisations in Belgium could save the country 209 million Euros per year, or over NZ$349 million based on the present exchange rate (Ramos et al., 2015).

Medication errors also have the potential to increase the use of primary care, increase medication-related hospital admissions, and sometimes result in death (Masotti & Green, 2010). Medication-related incidents account for 6-7% of hospital admissions in some countries, with approximately two thirds of those estimated to be preventable (Patel et al., 2007; Pirmohamed et al., 2004; World Health Organization, 2016b).

As medication errors are often considered preventable errors, the resulting effects on other areas of the health system are also considered preventable, and therefore crucial to minimise wherever possible (Bhuyan et al., 2015; World Health Organization, 2016b). In RACFs, medication errors are frequent, considering the sheer number and complexity of medications to be administered (Bhuyan et al., 2015).

2.6.1. Prescribing & Prescription Medication Errors

Prescribing and prescription errors generally take place in the beginning of the medication error cycle as they begin the medication process itself. Prescribing errors and prescription errors differ, but both relate to errors in the initial stage of medication treatment for a patient (Velo & Minuz, 2009). Prescribing errors relate to faults in the prescribing itself, such as irrational selection of a medicine or over or underprescribing of a medication, while prescription errors relate to errors occurring in the writing or otherwise generating of the prescription, such as illegibility (Aronson, 2009; Velo & Minuz, 2009).

Errors occurring in the prescription of a medication are some of the most researched of medication errors (Berdot et al., 2012); they are regarded as the most common of medication errors, accounting for 70% of occurrences (Velo & Minuz, 2009). This percentage varies across levels of care and pieces of research, but it is ordinarily the most commonly occurring type of medication error (Aronson, 2009). The likelihood of a prescribing error occurring increases with the age of the patient and with the number of medications prescribed (World Health Organization, 2016b). The higher likelihood of such errors occurring for elderly patients is likely a result of increased polypharmacy for older patients (Chan, Nicklason, & Vial, 2001; World Health Organization, 2016b).

Computerised physician order entry (CPOE)[6] systems, intended to support the prescribing process, have been proven to be instrumental in reducing the risk of these errors and resultant adverse drug events (ADEs), with the 2008 systematic review of Ammenwerth *et al*. finding a relative risk reduction of 13% to 99% for medication errors and a relative risk reduction of 35% to 98% for potential ADEs in comparing paper-based systems and less advanced HIT systems with electronic prescribing and CPOE systems (Ammenwerth, Schnell-Inderst, Machan, & Siebert, 2008). It was also found that electronic prescribing systems with advanced decision support had a higher relative risk reduction when compared to systems with limited or no decision support, particularly with regard to patient-specific alerts (Ammenwerth et al., 2008).

2.6.2. Dispensing & Manufacturing Medication Errors

Dispensing errors occur in the second stage of medication provision to a patient. When a prescription is generated, the medicine is then dispensed by a pharmacist; a dispensing error can occur anytime during this process (Aronson, 2009). Manufacturing errors, or errors in the makeup of the medicine formulation, also have the potential to occur here in the instance that a pharmacist is the manufacturer of the medication, like a cream or suspension (Aronson, 2009). In terms of medication supply to RACFs, dispensing errors usually take the form of the wrong drug, the wrong formulation, or the wrong label (Aronson, 2009). Dispensing errors, while not as common as prescribing errors, also have the potential to cause great harm to a patient; RNs, HCAs, and patients rely on pharmacists to provide the correct medication to administer or take; patients in particular are not likely to attempt to check or have the specialised knowledge to accurately check that the medication is as prescribed (Aronson, 2009).

2.6.3. Medication Administration Errors

As stated previously, there has historically been a paucity of research into elderly healthcare (Rolland et al., 2009); the same is true for medication administration errors, or MAEs (Berdot et al., 2012; Bhuyan et al., 2015). In research into ADEs and medication errors in both acute and residential care, the focus is most often on prescribing errors and dispensing errors rather

[6] Computerised physician order entry (CPOE) systems allow prescribers to prescribe medications for patients electronically (Sullins, A. Richard, Manasco, S. Phillips, & A. Gomez, 2012). Often CPOE systems provide decision support, drug interaction alerts, and drug information resources (Sullins et al., 2012; Vicente Oliveros et al., 2017).

than errors occurring at the medicine's administration (Berdot et al., 2012). This trend is mirrored in evaluating the efficacy of new EMM products (Guo et al., 2011). In the case of RACFs, care staff are the last barrier before a medication is administered to a patient (Berdot et al., 2016; Guo et al., 2011). MAEs are therefore as crucial to measure as prescribing and dispensing errors, especially considering that the majority of preventable ADEs occur in the prescribing or administering stage of the medication management process (Philip Aspden, Corrigan, Erickson, Wolcott, & Erickson, 2003; Guo et al., 2011). Further, in hospital settings, administration errors are the most common type of error to occur in a patient's care, and medication administration is the stage most susceptible to error of the medication management process (Ghazi Aziz, Aboobaker Osman, & Authman Rasheed, 2018; A. Tariq et al., 2014). Most MAEs occur as a result of human error rather than faulty processes (Ghazi Aziz et al., 2018). Typically, MAEs fall into one of the following categories (Aronson, 2009; Fuller et al., 2018; Szczepura, Wild, & Nelson, 2011; H. M. Young et al., 2008):

- Wrong resident (medication given to or attempted to be given to the wrong person)
- Wrong time (administration of medication at the incorrect time)
- Wrong dose (administration of the incorrect dose of medication)
- Dose omission (omitted dose of medication)
- Wrong medication (wrong medication given to or attempted to be given to the resident)
- Unauthorised medication (medication given to or attempted to be given to the resident which is not currently signed for by a prescriber)
- Deteriorated drug error (expired or otherwise contaminated or compromised medication given to or attempted to be given to the resident)

Problematically, MAEs not only affect the health of the offended patient or patients; the health of those committing the MAE can also be affected, generally through psychological distress and a decline in confidence (Ghazi Aziz et al., 2018). Near-miss events also commonly occur, in which a MAE is intercepted prior to being committed (Durham, 2015). As difficult as it is to track MAE rates, it is even more difficult to track how many near-miss events occur as these are generally not reported and have the potential to go entirely unnoticed (Durham, 2015; Szczepura et al., 2011). It should be noted that a completely error-free environment is unrealistic and should not be expected (Durham, 2015).

It is difficult to gauge how often MAEs occur. Bates *et al*. reported 34% of all medication errors occurring in the administration stage, rendering medication administration one of the most error-prone phases of the medication process (Bates et al., 1995). Within the aged care sector, Ferrah *et al.* (2017) reported in a recent systematic review that medication errors occur with 16-27% of all RACF residents, with 20-60% of those errors occurring in the administration or ordering step of the medication administration process (Ferrah, Lovell, & Ibrahim, 2017; Fuller et al., 2018). However, MAE rate parameters in RACFs are generally wide, ranging from 3-50% (Barber et al., 2009; Barker, Flynn, Pepper, Bates, & Mikeal, 2002; Fuller et al., 2018; Scott-Cawiezell et al., 2009; Scott-Cawiezell et al., 2007; Tenhunen, Smithers, & Tucker, 2016; H. M. Young et al., 2008; Zimmerman et al., 2011). Zimmerman *et al*. found that 42% of all medication administrations among twelve assisted living communities involved an error, though when time-related medication administration errors were omitted, this was reduced to 20% (Zimmerman et al., 2011).

2.7. Reporting of Medication Administration Errors

Medication error information is routinely collected by RACFs as part of their quality improvement policies and procedures and audit requirements (Amina Tariq, Georgiou, & Westbrook, 2012b). By policy, medication errors in residential healthcare facilities are reported using structured incident forms designed by the organisation and based on governmental guidelines (Amina Tariq et al., 2012b); these can be reported by the care staff member(s) involved in the incident or by other care staff members who witnessed the incident (Seibert et al., 2014). The staff member reporting the incident must also advise management staff as soon as is reasonably possible, regardless of the severity of the incident (Amina Tariq et al., 2012b). Voluntary reporting of medication incidents is the most common method of medication error reporting, though it can also be considered the most flawed method due to underreporting (Seibert et al., 2014). Voluntary reporting is likely to not only underreport on the frequency, outcomes, and sheer number of medication errors - it also does not include near-miss events, which are common (Durham, 2015; Seibert et al., 2014). Voluntary reporting is often used in conjunction with manual chart review, in which a senior clinical staff member reviews the charts comprehensively or at random in order to identify discrepancies (Seibert et al., 2014). Problematically, medication errors identified as a result of manual chart review are not often found within a timely manner (in the sense that they are reviewed after the administration of medications) and therefore may prove too

late for appropriate action to be taken. Computerised medication chart monitoring is also used, though this may be less effective than manual review (Jha et al., 1998; Seibert et al., 2014). The gold standard of medication administration error detection and documentation is direct observation of staff administering medications (Seibert et al., 2014). However, such a method of error identification is resource-intensive and as a result is used only for short periods of time; direct observation is often used only during audits or for research purposes (Seibert et al., 2014). The ideal in such a situation would be to conceal the observer from the observed, as it may be that the potential for administration errors in a knowingly observed situation differs from administration errors occurring in an unobserved setting; for example, some medication administrators might perform better during observation in what is known as the Hawthorne effect (Poon et al., 2010; Sedgwick & Greenwood, 2015).

Computerised medication error monitoring, intervention, and prevention is a component of some electronic medication administration methods, though such methods, like barcode medication administration (BCMA), are more common in acute care settings rather than residential care settings (Berdot et al., 2012; Seibert et al., 2014). Seibert *et al*. (2014) found that BCMA-eMAR systems to be more reliable in terms of recording, intercepting, and preventing medication errors than voluntary reporting (Seibert et al., 2014). Possibly the most effective method of both tracking and prevention of medication administration errors, these technologies provide more accurate data around medication error occurrence as well as provide a glimpse of medication administration error potential (Ammenwerth et al., 2008; Helmons, Wargel, & Daniels, 2009; Maddox, Danello, Williams, & Fields, 2008; Seibert et al., 2014).

2.8. Electronic Medication Management

With the emergence of health information technology and increase in confidence in information technology security, many health care systems have begun a gradual move from paper-based records toward centralised paperless processes. Numerous benefits can be attributed to switching from paper-based systems to electronic systems, including legibility, accessibility, and efficiency; the evolution of information technology directly impacts patient safety in healthcare (Guo et al., 2011; Koppel, Wetterneck, Telles, & Karsh, 2008). With medication a key component in the modern healthcare system, electronic medication management (EMM) naturally became a main focus and has begun implementation in New Zealand and around the

world. Development in this area is especially pertinent in the residential aged care arena given the growing volume of medicines prescribed per patient and residents' complete reliance on health care professionals for correct medicine administration (Archer, 2015). As health care systems, laws, and resources differ from nation to nation, the systems used vary to accommodate different needs, including the information exchange between clinicians involved in an RACF patient's care (Amina Tariq, Georgiou, & Westbrook, 2012a). Major concerns in this area involve the design of medication charts and the communication between prescribers, pharmacists, and care staff involved in care of a patient (Amina Tariq et al., 2012a). There is potential for EMM systems to assist in these difficulties. A primary component of EMM is the eMAR, or electronic medication administration record; this is the signing sheet within EMM solutions. Barcode medication administration and eMARs have been prominent strategies to reduce medication administration errors in RACFs (Fuller et al., 2018).

2.8.1. Barcode Medication Administration

BCMA systems are known to reduce medication administration errors in hospital level care (Fowler, Sohler, & F Zarillo, 2009). They provide a mechanism for medication management throughout the process from entry of the medication order through to delivery of medication to the patient (Fowler et al., 2009). Medicine administrators are supported through their required checks of the patient and the medications; using handheld bar code readers, medicine administrators are able to scan a patient's bar code identifier immediately prior to medicine administration to verify certain aspects of medication administration, including the patient's identity (Seibert et al., 2014; Shah, Lo, Babich, Tsao, & Bansback, 2016; Staggers, Iribarren, Guo, & Weir, 2015; Szczepura et al., 2011). The barcode scan recalls a patient profile, usually on a handheld tablet device or a mobile computer, for the medicine administrator to visually confirm that it is the correct patient (Seibert et al., 2014; Szczepura et al., 2011). The medicine administrator's identification badge and each dispensed item is also scanned individually completing the remainder of the five 'Rights' of medicine administration - correct patient, medication, dose, route, and time (Fowler et al., 2009; Shah et al., 2016; Staggers et al., 2015; Szczepura et al., 2011). Any potential errors are alerted to the medicine administrator, and the medicines' administrations are recorded against the administrator's name, provided by the identification badge (Szczepura et al., 2011).

BCMA technology is most often used in more acute settings, such as hospitals, rather than in residential aged care (Berdot et al., 2012). Helmons *et al*. conducted an observational before-and-after study examining MAEs following implementation of a BCMA system across four units of an American-based hospital, including two medical-surgical units and two intensive care units (ICU) (Helmons et al., 2009). While MAEs decreased in the medical-surgical units following BCMA implementation, when wrong time errors were excluded from the results, MAEs did not decrease in the ICU (Helmons et al., 2009). The rate of wrong time errors did not change in either care level following BCMA implementation (Helmons et al., 2009). Notably, BCMA implementation in this study improved quality of charting and medication labeling in the ICU care level (Helmons et al., 2009); while compliance in patient identity confirmation prior to drug administration increased with the BCMA system, so did the number of interruptions and distractions during the medication administration process (Helmons et al., 2009). In the ICUs, no significant differences were found in the types of medication administration errors occurring before and after BCMA implementation, whereas the medical-surgical units demonstrated a substantial reduction in the number of omitted medications following BCMA implementation (Helmons et al., 2009); the study highlights the importance of examining HIT implementation effects in different areas of care rather than at facilities as a whole (Helmons et al., 2009). However, the system used in this study was integrated with various other HIT systems, including the CPOE system and the pharmacy's information system, which may have also impacted medication error rates (Helmons et al., 2009).

BCMA systems have assisted in substantially reducing preventable errors involved with medicine administration in acute hospital level settings (Shah et al., 2016; Staggers et al., 2015). Australia has also begun moving toward HIT to improve clinical efficiency (Qian et al., 2015; Sluggett, Ilomäki, Seaman, Corlis, & Bell, 2017; Yu, Zhang, Gong, & Zhang, 2013). Some hospital-level care in Australia employ BCMA technology in medication administration, and many Australian RACFs employ eMARs in place of the paper National Residential Medication Chart (Jackson & Welsh, 2017). The systems in use were developed for medication administration and have advanced to include real-time data on care plan changes, better reporting on medication adherence, and stock ordering (Jackson & Welsh, 2017). Prescribers chart medications directly into the system for administration, but the chart must be printed and signed in order to abide by Australia's requirement for a physical signature on patient medication charts (R. A. Elliott, Lee,

& Hussainy, 2016). After the medications are charted and signed for, the pharmacy dispenses the medications to the RACF (R. A. Elliott, Lee, & Hussainy, 2016). At the point of care, medication administrators log into the systems on portable touch screen devices using usernames and passwords, like the New Zealand systems; a list of RACF patients with medications due during the current medication round is displayed (Jackson & Welsh, 2017; Qian et al., 2015). Upon selecting a patient to whom to administer medications, the medication administrator must confirm various pages of information about the patient, including photo, names, and allergies (Qian et al., 2015). Medications given are stamped with the username of the medicine administrator and the time of administration; medications not given must have a reason provided as to why, compelling adequate documentation (Qian et al., 2015). Data resulting from the medication round is stored on the portable device and can be synchronized with the RACF's database at the end of the round (Qian et al., 2015).

2.8.2. Electronic Medication Administration Records

Electronic medication administration records, or eMARs, form the foundation of EMM, regardless of the type of system used. eMARs have been widely used in practice in hospitals and residential institutions in Europe and the United States for the last decade (Alenius, 2016; Berdot et al., 2016; Guo et al., 2011; Shah et al., 2016; Vicente Oliveros et al., 2017). eMARs are the electronic equivalent of a paper signing sheet in an EMM system; RACF staff therefore rely on the eMAR's accuracy in order to avoid errors (Guo et al., 2011; J. Taylor, 2017). All EMM systems, like BCMA, in which medicine administers record medicine administrations have some version of an eMAR in which medicine administrations can be recorded. eMAR programs are also available as standalone products; these are typically targeted more at residential care than acute care (Fuller et al., 2018). As acute care centres such as hospitals often have larger integrated HIT systems supporting the eMAR systems in place, the standalone eMAR program might be considered a smaller, more affordable alternative for RACFs with potentially the same benefits (Fuller et al., 2018).

eMARs have varied in structure and form over the years depending on the level of care and how the eMARs are generated (Guo et al., 2011). For example, depending on national legislation, an eMAR can be populated by importing information from electronic health records (EHRs), via

computerized order entry by prescribers, through export from an electronic pharmacy dispensary system, or by manual entry by prescribers (Guo et al., 2011).

eMAR system processes vary from country to country due to a variety of factors; not only are their designs dependent on nationally-specific legislation, but also on the type of care provided (A. Tariq et al., 2014). The core function of an eMAR, however, remains the same. The evolution of eMARs has resulted in many countries in Europe, like England, Spain, and Sweden implementing bar code medication administration (BCMA) systems in hospital and RACF settings (Szczepura et al., 2011; Vicente Oliveros et al., 2017).

2.9. Benefits of Electronic Medication Management

Benefits of EMM system use in hospital and RACF settings have been a driver in EMM development, implementation, and even subsidization around the world (Siska & Tribble, 2011). Many of these benefits relate to improved medication safety. There is a general paucity of research analysing MAE occurrence in New Zealand RACFs, but with the expansion of information technology into the healthcare sector throughout the world, research has been produced in other nations (Bhuyan et al., 2015; Fuller et al., 2018). HIT systems' effects on medication errors have been studied predominantly in the acute care sector, with comparatively little research conducted in aged care (Fuller et al., 2018). Research has predominantly focussed on BCMA systems and EHR systems due to their popularity in high-level care facilities for both acute and residential care (Fuller et al., 2018; J. Young, Slebodnik, & Sands, 2010); furthermore, RACFs have been slower on the uptake of HIT, resulting in comparatively little empirical research in this area (Broughton, Lashlee, Marcum, & Wilson, 2013).

Poon *et al*. (2006) found a 41% reduction in medication administration errors unrelated to timing and a 51% reduction in potential ADEs resulting from medication administration errors in their research evaluating a BCMA system in an acute hospital setting (Poon et al., 2010). The system evaluated in the study was closely integrated with the pharmacy's dispensary software, better allowing pharmacists to clinically review charted medications, potentially preventing errors and resultant ADEs as medicine administrators could only administer medications following the pharmacists' review (Poon et al., 2010). The research suggested the avoidance of potential ADEs after the BCMA system's implementation may be due directly to the reduction in documentation errors, noting that this renders the eMAR component of the BCMA technology, or the medication

administration module, more effective at preventing medication errors than the medication-verification component of the BCMA system (Poon et al., 2010). The hospital in the study, however, also had a CPOE system integrated with the BCMA system, possibly increasing effects when compared to a standalone BCMA or eMAR system (Poon et al., 2010).

Szczepura *et al*. analysed the incidence of medication administration errors in thirteen RACFs, nine of which were low-level care and the remaining four hospital level care, all of which were using a BCMA system (Szczepura et al., 2011). It was found that 90% of residents were exposed to at least one medication error over the 3-month period of observation, so medication administration errors were not occurring only with a group of certain residents (Szczepura et al., 2011). Residents were exposed to 6.6 potential medication administration errors throughout the observation period (Szczepura et al., 2011). Error rates were overall higher in the hospital level care units, despite RNs being the only medicine administrators in these areas; however, this is supported by medicine administrators' impressions at the RACFs identifying that lack of education or training was not the cause of error, but rather interruptions and distractions during the medication rounds (Szczepura et al., 2011). The higher rate of errors in the higher level of care could also be explained by the increased complexity of medical cases in those units when compared to the lower level of care, resulting in more complicated decision-making processes for the medicine administrators (Szczepura et al., 2011).

In Seibert *et al*.'s 2014 study evaluating the effect of BCMA and eMAR technology on medication accuracy rates in two acute care hospitals, introduction of the system significantly increased medication accuracy rates across all units involved in the study, and no new medication administration error types were found following implementation (Seibert et al., 2014). MAE frequency significantly decreased following the BCMA and eMAR system implementation (Seibert et al., 2014).

In their research on the impact of eMARs in an RACF, Qian *et al*. found several benefits associated with eMAR use, including RN compliance with documentation requirements, removing the ability to sign for the medication twice, reducing potential for RNs to forget to administer a medication, enabling the recording of a medication's administration time, and increasing documentation space for medicine administrators (Qian et al., 2015). Documentation requirement improvements are beneficial in that the eMAR enabled RNs to better adhere to organisational requirements like completing medication administration for one resident prior to moving on to the

next resident's medication administration (Qian et al., 2015). The eMAR facilitated timeliness of medication signing rather than giving several residents' medications before proceeding to sign their charts, which sometimes occurred with the paper-based system (Qian et al., 2015). Double-signing the same medication and forgetting to administer a medication were problematic in the paper-based system due to the possibility of signing off the same medication administration under two different dates and not receiving reminders if a medication was not signed off respectively (Qian et al., 2015). The eMAR system alleviated these errors by displaying only the selected medication round and by prompting medicine administrators when a medicine had been missed or not signed off (Qian et al., 2015). When medicines were signed off, the eMAR system automatically recorded the time and date of the medicine's administration, negating the need for a medicine administrator to remember the time of administration from an earlier round – he or she could simply refer to the date and time stamped on the medicine's administration (Qian et al., 2015). Additionally, the study found the time medicine administrators took to find and read a resident's profile one the eMAR was significantly reduced compared to the paper-based system, but this may not be important with regard to reading the medications in the profiles as the medicine administrators in the study were familiar with the residents' medications (Qian et al., 2015).

Oliveros *et al*. evaluated the effect of an eMAR application on the rate of MAEs in a university hospital in 2014, finding a significant decrease in the error rate following eMAR implementation (Vicente Oliveros et al., 2017). As with the EMM system examined in this research, implementation of the eMAR solution used in that study involved changes to the facility's workflow, including standardisation of dose times and providing justifications for omitted doses (Vicente Oliveros et al., 2017). The types of administration errors analysed were classed as errors which could have occurred in both the paper-based and eMAR settings (such as such as wrong time errors), errors resultant of human error or technical problems (such as workarounds), or clinical errors (clinical errors unique to the eMAR application, more likely to occur with the eMAR, more likely to cause harm with the eMAR, and which made no difference between systems) (Vicente Oliveros et al., 2017). All classes saw decreases in the medication error rate after the eMAR implementation (Vicente Oliveros et al., 2017). MAEs resultant of incomplete information did not occur following eMAR implementation, as did 'wrong medication' errors; 'wrong time' errors significantly decreased (Vicente Oliveros et al., 2017).

In a recent systematic review, Fuller *et al*. investigated research into the effectiveness and perceptions of eMARs, identifying three broad themes investigated in the included studies: medication and MAE rates, benefits and challenges of eMARs in RACFs, and eMAR prevalence and uptake (Fuller et al., 2018). All studies reporting on MAE rates following eMAR implementation noted a reduction in incidence of medication administration errors, though the error types and severity of errors prevented or occurring were not noted in any of them (Fuller et al., 2018). Unsurprisingly, reporting capabilities were found to have improved with eMAR implementation (Fuller et al., 2018).

Another recent systematic review by Kruse *et al.* identified four of 28 reviewed studies, or 14%, reporting improved health outcomes in aged care settings, accounting for 9% of occurrences reviewed following implementation of EHRs in long-term care facilities (Kruse et al., 2017; Qian et al., 2015; Rantz et al., 2010; Yu et al., 2013; Zhang, Yu, & Shen, 2012); this is to be expected considering the slower uptake in HIT adoption in RACFs due to little significant literature demonstrating long-term quality improvement and decreased costs (Ajami & Bagheri-Tadi, 2013; Kruse et al., 2017). Medication safety was mentioned in only two of the reviewed papers, despite being a major potential benefit of electronic records in healthcare (Brankline, Coyle, Jencks, Mullegama, & O'Brien, 2009; Kruse et al., 2017; Scott-Cawiezell et al., 2009). Health outcomes, however, were a common theme, which included timely medication (Kruse et al., 2017; Rantz et al., 2010; Zhang et al., 2012). Human errors were shown to have reduced, including neglecting to administer medication to residents (Kruse et al., 2017; Qian et al., 2015).

2.10. Barriers, Challenges & Consequences of Electronic Medication Management

While the benefits of EMM use are recognisable at this stage, some barriers have also been realised. There may be unexpected negative consequences to the introduction of new EMM systems and indeed any new HIT system, further contributing to the necessity of comprehensive review of new systems put into place. The presumed benefits of electronic healthcare documentation are expected to outweigh the consequences, but the negative aspects of each system should also be analysed to prevent unanticipated consequences to patient care. Some immediate benefits to BCMA and eMAR medication administration are demonstrated, such as improved communication between clinicians involved in patient care, improved legibility and accuracy of and access to charts, timeliness of chart updates, quality of care, and overall patient safety (R. A.

Elliott, Lee, & Hussainy, 2016; Zadvinskis et al., 2013). However, there are also barriers to implementing an EMM system, such as lack of financial resources, staff shortages, and little incentive in planning, implementing, and training staff for a new model of patient care (Bhuyan et al., 2015; Stefanacci, 2008).

Qian *et al*. found several consequences in their study, including inadequate readily available information about past medication administrations, late addition of a new resident's profile and medication chart, and the battery life of the portable devices used (Qian et al., 2015). In a paper-based system, the day and month of medicine administrations are quickly available, whereas the eMAR displayed recent medicine administration information only on the desktop computers rather than the devices used at the point-of-care (Qian et al., 2015). The late addition of a new resident's profile to the eMAR is a major concern as this results in a temporary hybrid system of both paper and eMAR, meaning a medicine administrator must remember there is a paper record to sign off in addition to the residents on the eMAR (Qian et al., 2015). Battery life of the portable devices used at the point-of-care for eMAR is an adjustment to the always available paper signing sheets, but this can be addressed with practice or backup devices (Qian et al., 2015). However, not all technological challenges are solved with day-to-day use and backup devices; comprehensive organisational policies and procedures are also necessary in preparation for emergencies, such as power outages in the middle of a medication round reported by Qian *et al*. (2015), forcing medicine administrators to resort to memory in order to continue their medication administration (Qian et al., 2015). A consequence common between both paper and electronic systems was the documentation of how a resident takes a medication, e.g. with a spoon, with yoghurt, with water, *etc* (Qian et al., 2015). While this can be documented by the prescriber in the 'Special Instructions' section of both systems, it often is not, and neither system readily permits an RN to document how the resident takes a medication (Qian et al., 2015).

Guo *et al*. conducted a heuristic evaluation of the usability of an implemented eMAR system from the RN's (medicine administrator's) perspective, noting that past EHR studies have not focussed on the eMAR (Guo et al., 2011). Usability, or the extent to which a product "allows the user to execute his task effectively, efficiently, and with satisfaction in the specified context of use," is a crucial aspect of any new HIT system in order to avoid any increase in human error following system implementation, especially considering the technological experience among medicine administrators can vary enormously (Abran et al., 2003; Guo et al., 2011). Some issues

included visibility around overdue medication alerts, the ability to sign off narcotic medications earlier than their assigned chart time, lack of integration between modules, and possibility of workarounds to better fit the RN's thought processes and work design (Guo et al., 2011).

While Kruse *et al.*'s (2017) review noted a reduction in medication errors across 11% of the studies reviewed, these were inclusive of prescribing, dispensing, and documentation errors; it was not specified whether EHR use diminished MAEs (Kruse et al., 2017; Munyisia, Yu, & Hailey, 2011; Sockolow, Weiner, Bowles, Abbott, & Lehmann, 2011; Zhang et al., 2012). Also noted was the issue with some information being recorded electronically and some on paper, leading to potential double-handling or missed information (Kruse et al., 2017). As the system used in this research is an electronic charting and medication administration system only, it does not comprehensively contain all documentation associated with a patient's care. For example, a patient's progress notes are still documented on paper, and the patient management system is separate to the system used in the present study.

Workflow or process deviations are relatively common in RACFs (Qian, Yu, Hailey, Wang, & Bhattacherjee, 2018). Workarounds are used in both paper-based and EMM systems in order to conform to the care staff's mode of operation, to circumvent issues where the software is note deemed sufficiently flexible, and to overcome processes that are cumbersome for medicine administrators (Koppel et al., 2008; Qian et al., 2018). Fuller *et al.*'s (2018) systematic review reported technology-related challenges such as internet instability or hardware issues as well as challenges relating to adequate training and technology support (Fuller et al., 2018). Some issues reported involved the design of the eMAR system itself, including a dearth of decision support, minimal interactivity between facility and pharmacy, and poor information layout (Fuller et al., 2018). Workarounds were also reported to bypass difficulties with eMAR design, technological issues, and organisational processes (Fuller et al., 2018). No workaround processes were observed during Szczepura *et al.*'s (2011) study, and there was a high level of acceptance of the BCMA system by the staff using it (Szczepura et al., 2011); however, the main cause of error in both pre-implementation and post-implementation stages of Oliveros *et al.*'s study was failure to follow work procedures, highlighting that despite improved accuracy and quality of medication administration with the eMAR application, external factors like interruptions, distractions, and high workload do not reduce with eMAR implementation (Vicente Oliveros et al., 2017). However, there was an overall significant decrease in potential future risk to patient safety (Vicente

Oliveros et al., 2017). Notably, this study was focussed on the eMAR application in isolation rather than in conjunction with implementation of other systems, like electronic prescribing, that may also have an impact on patient safety (Oliver, Raban, Baysari, & Westbrook, 2013; Vicente Oliveros et al., 2017). However, it should also be noted that the eMAR application evaluated in Oliveros *et al*.'s study was integrated with a CPOE system – nearly 50% of the errors occurring with the use of the eMAR were related to this integration and incorrect prescriptions, denoting the importance of comprehensive training and straightforward usability (Vicente Oliveros et al., 2017). The perceived usefulness of applications being adopted are also crucial, otherwise there may be barriers to implementation and uptake (Zadvinskis et al., 2013). Not all medication errors were eliminated in Poon *et al*.'s 2006 study either (Poon et al., 2010), and it is unlikely that all medication errors will ever be completely eliminated due to human error – in order to reap the full benefits of any EMM system, the system must be used as intended, further highlighting the need for effective and comprehensive training for users (Poon et al., 2010).

2.11. User Perceptions of Electronic Medication Management

When implementing or designing EMM systems, the users and their workflow must be carefully considered. Fowler *et al*. (2009) examined nurses' reception to BCMA technology in an acute hospital setting; nurses in the study reported they perceived the BCMA technology to be safer than the previous system, but errors increased in the immediate months following the system's implementation; acceptance of the change was expected to rise with time, but it was noted that material issues (such as inadequate space on the medicine trolleys) may have contributed to staff dissatisfaction during the medication administration system transition (Fowler et al., 2009).

In Clarke *et al*.'s qualitative study on the impact of electronic health records in an English teaching hospital, medicine administrators perceived the introduction of the system as increasing the possibility of errors due to a lack of familiarity with the system and having less room but more places to put information, making records disjointed and potentially lacking in crucial information like allergies and test results (Clarke et al., 2016). It was also noted that staff involved in the study found the system difficult to navigate (Clarke et al., 2016); data entry methods were inflexible and consisted predominantly of tick boxes and drop-down suggestions, thought to further increase the risk for errors (Clarke et al., 2016). Furthermore, consulting clinicians did not have access to patient information prior to consultations, negatively affecting quality of care (Clarke et al., 2016).

The study established that while research regarding electronic records in acute care has tended toward examining the benefits of such systems, like reducing errors and adverse drug events, few examine how the risks to patient safety can be increased by them, as with human error and technical issues and adjustments (Clarke et al., 2016).

Fuller *et al.*'s (2018) systematic review noted that medicine administrators using eMARs reported lower stress levels of medication administration and perceived the eMAR system as decreasing the number of medication errors and that patient care was felt to be safer (Fuller et al., 2018). Workflow efficiency was reported to improve with eMAR implementation, especially when the eMAR was integrated with an associating EHR or CPOE system (Fuller et al., 2018).

Vogelsmeier *et al.* found that the eMAR used in their research at five RACFs was designed with several software components of intentional workflow inertia to promote patient safety, such as documenting that the medications were prepared for the resident prior to administration, then documenting following administration of medication to the resident (Scott-Cawiezell et al., 2009; Vogelsmeier, Halbesleben, & Scott-Cawiezell, 2008). Care staff, however, bypassed these blocks in considering them too time-consuming (Scott-Cawiezell et al., 2009; Vogelsmeier et al., 2008). This demonstrates that safety mechanisms in HIT must still be acceptable to the user (Scott-Cawiezell et al., 2009; Vogelsmeier et al., 2008).

Elliott *et al.*'s recent study focussed on the response of prescribers, pharmacists, and RNs to EMM system implementation in Australian RACFs, highlighting two main themes in the benefits of the EMM system used – patient safety and workforce efficiency (R. A. Elliott, Lee, & Hussainy, 2016). While the EMM system in the study included electronic prescribing, the system is similar to the system examined in this study in that what was prescribed in the system was automatically transmitted to the eMAR part of the system, allowing medicine administrators to give medications based directly on what the prescriber entered into the system (R. A. Elliott, Lee, & Hussainy, 2016). GPs and RNs reported that remote access for changes was useful for both patient safety and workflow efficiency as changes are automatically reflected on the eMAR in the RNs' view (and GPs did not need to leave the clinic to make changes, while the RNs could see changes in a timely manner), and pharmacists reported that no longer having to interpret GP handwriting improved safety (R. A. Elliott, Lee, & Hussainy, 2016). Limitations of the system highlighted three main themes: inefficiency, GP uptake, and training and support (R. A. Elliott, Lee, & Hussainy, 2016). Pharmacists and RNs noted that the potential benefits of the EMM system

were there, but without the appropriate uptake by GPs, those benefits would be difficult to realise (R. A. Elliott, Lee, & Hussainy, 2016). This is crucial as prescribers begin the medication process for RACF patients, making them drivers in the EMM transition. The use of different EMM systems at different RACFs was also seen as a barrier, as GPs then must learn to use multiple EMM systems rather than just one (R. A. Elliott, Lee, & Hussainy, 2016). Additionally, GPs reported that paper-based charting was quicker, and that as a standalone system without integration into their practice software and without decision support, the system offered GPs little advantage over paper-based systems (R. A. Elliott, Lee, & Hussainy, 2016).

2.12. New Zealand Options for Electronic Medication Management in Residential Care

Two relatively similar cloud-based aged care EMM systems are currently available in New Zealand, including a commercial product referred to here as System *X*. System *X* was developed in consultation with clinicians involved in RACF patient care, including pharmacists, GPs, and RNs. Both systems require each user to log in online using a username, password, and two steps of authentication in the form of security questions or input of a PIN number. The user's login constitutes his or her electronic signature, and the view or information available to each user relies on the role they are assigned based on their role in the patient's care (Prescriber, Pharmacist, Nurse, HCA, etc.). In 2015, the Ministry of Health granted the systems an exemption from the requirement for a physical signature, meaning prescribers do not have to print and physically sign the charted medications prior to their administration – charting medicines while logged into the system suffices as the systems stamp each charted medication with the name of the prescriber who charted it (HealthCERT, 2015). However, when a medication is charted, a prescription must be raised, either by written script, telephone script, or ePrescribing[7] for the medicine to be given to the patient.

In the interest of chart auditing compliance and by proxy, patient safety, when charting a medication for a patient in System *X*, the prescriber is compelled to input required information, such as route and unit of administration, indications for as-required or *pro re nata* (PRN) medications, and the time and frequency at which regularly charted medications are to be given.

[7] New Zealand's electronic prescribing service, or NZePS, is a relatively new system through which a prescriber can generate a prescription for a patient to be transmitted via the NZePS system and downloaded electronically by a pharmacy's dispensing software (Ministry of Health, 2019b; Patients First, 2013). This allows prescribing and dispensing software to safely and efficiently exchange prescription information, including notifying the prescriber when the medicine has been dispensed to the patient (Ministry of Health, 2019b).

While the prescriber can chart on a 24-hour clock, they can also choose to chart the medications for a standard medication round, such as for breakfast and bedtime. In System *X*, clinical leads at the RACF select the parameters around standard medication round times, or default timeslots, to accommodate the time the staff take to administer medicines to the whole facility as this can vary from facility to facility based on size, staffing levels, and the level of care. Prescribers are provided the parameters of the default timeslots when charting.

After a prescriber electronically charts medications for their RACF patients in System *X*, the pharmacy receives a notification to dispense. Simultaneously, an eMAR is generated from the chart, detailing for medicine administrators when medications are to be given and how they are to be administered. Medicine administrators receive an alert per patient based on the timeframes that medications are due; upon selecting the patient to whom they are administering medication, the medicine administrators are provided an eMAR containing only medicines due for the patient that day. The medicines due at the present time are highlighted, have the dose bolded, and have tick boxes next to them to indicate that they are due to be given. The medicine administrators are then able to perform their 5 Rs + 3 checks against what is due and tick the medicines. After they have administered the medicines to the patient, the medicine administrators press a 'Given' button, indicating the ticked medicines have been given. If any medicines have not been given for any reason, the medicine administrators untick those medicines prior to pressing 'Given'; after signing off the given medicines, the medicine administrators re-tick the not given medicines and press a 'Not Given' button. Any time a medicine administrator is signing that a medicine is 'Not Given', a reason must be provided. In the case of System *X*, the reason is compelled as the medicine will not save as 'Not Given' until a reason has been provided. A drop-down list of common reasons, such as refusal or withholding, is available, and a free-text field is an option in case of any unusual circumstances. The prompting of a medicine administrator to provide necessary information about medicine usage or administration is intended to improve documentation and increase compliance with organisational policy, providing a better all-around picture of a resident's medicine experience in an RACF. Not only is this easier for management and auditors to interpret, but it also ensures a medicine administrator has always provided a reason for taking a particular action, like administering a PRN or electing not to administer a medication due to resident refusal.

Having the prescribers select a timeframe for all regular medicines not only assists System *X* in producing alerts at the correct time a medication is due, but also is intended to make it quite

difficult for RACF staff to miss a charted medication. If a medication has not been given within the timeframe charted by the prescriber (whether the medication be due during a typical medication round, such as Breakfast or Lunch, or at a specific time, such as 1400), medicine administrators are provided a patient-specific alert indicating that a medication has been missed. The alert will remain for 72 hours following the due time of the medication or until the medicine has been signed off as 'Given' or 'Not Given' by a medicine administrator. Any time a medicine is signed off outside of its charted parameters, System *X* requires a reason as to why be provided by the medicine administrator for auditing purposes. The symbol advising a medicine has been signed off outside of its charted parameters advises other staff that a medication may have been given late; this is intended not only to promote medications being given on time, but also serves to advise of medications given late in case a minimum time between regular doses is required (e.g. pharmacists advise a minimum of four hours between doses of paracetamol).

As the pharmacy dispenses the medicines to the facility, the brands dispensed are selected in System *X*, providing a photo of the tablet or capsule if one is available. In System *X*, over 1,100 are currently available. This may be especially helpful for HCAs, who may not know what they are looking for in a dose pack. System *X* is integrated with many pharmacies' dispensary systems (approximately 86% across New Zealand), further assisting the accuracy of pill pictures for dispensed medications by matching what is charted in System *X* with what is dispensed in the pharmacies' dispensary systems. System *X* is not integrated with prescribers' clinic software, patient management systems, or prescribing systems.

System *X* was designed predominantly from the perspective of an RN as medicine administrators were considered to be the most frequent users of the system. As a result, the nursing workflow within a residential facility was considered in the design of the product, as the potential benefits of such a system would be largely diminished if it failed to support the workflow of medicine administrators (Helmons et al., 2009).

A major focus of HIT adoption in hospital settings has been with the aim of decreasing medication errors (Philip Aspden et al., 2003; P. Aspden, Wolcott, Bootman, & Cronewett, 2007). When evaluating the efficacy of new EMM products, the focus is more often than not on errors in the prescribing and dispensing of medications rather than errors in administration (Guo et al., 2011). Care staff in RACFs are the last barrier before a medication is administered to a patient (Berdot et al., 2016; Guo et al., 2011); administration errors are equally crucial to measure,

especially considering the majority of preventable adverse drug events (ADEs) occur in the prescribing or administering stage of the medication management process (P. Aspden et al., 2007; Guo et al., 2011). As indicated earlier, the levels in training varies among medicine administrators in RACFs, and as the need for and complexity of aged care increases, HCAs are taking on more and more medication-related tasks at RACFs. With HCAs administering medications to RACF patients with limited knowledge of the medications themselves, it is imperative to empirically note if the EMM systems in place in New Zealand RACFs are actively reducing the rate of medication administration errors. Further to this, it is crucial that any unprecedented medication administration errors have not been introduced with the implementation of a new system (F. Magrabi et al., 2012; Farah Magrabi, Ong, & Coiera, 2016; Vicente Oliveros et al., 2017), especially considering studies evaluating patient safety in HIT often measure effects of multiple HIT systems' concurrent implementation, like eMAR and electronic prescribing (Oliver et al., 2013).

2.12.1. Implementation of System X in Residential Care

Implementation of System *X* takes between four and six weeks per RACF. The implementation period involves the RACFs' contracted pharmacy moving the dose pack information from their dispensary system into System *X*, setting up a skeleton chart including only the basics: national health index (NHI) number[8], full name, date of birth, and some to all current medicines. If the pharmacy is using System *X* for the first time, the staff are trained by a System *X* staff member in how to prepare dose pack information and then to generate the charts in System *X*. The pharmacy staff then check the newly generated electronic charts against the information in their dispensary system, adding any missing medicine information as usually only packed medicines are exported automatically[9]. A remote or live training is then undertaken with the clinical management team of the RACF by a System *X* staff member to demonstrate how to

[8] A National Health Index (NHI) number is a unique identifier assigned to each person requiring health care in New Zealand (Ministry of Health, 2018b). As the number is unique to each individual, it supports medical record maintenance and ensures the right information is readily available to health professionals who may need access to that information for patient care (Ministry of Health, 2018b).

[9] Packed medicines are medications which are dispensed into specialised containers by dose (Ministry of Health, 2011c, 2013a). The containers, usually blister packs (sealed plastic tubs) or plastic sachets, detail what is inside the pack and contain only the doses due at the given drug round (Ministry of Health, 2011c). These medicines are usually tablets or capsules (Ministry of Health, 2011c). Non-packed medications are loosely packaged, which is to say they are not packaged by individual doses (Ministry of Health, 2011c). At RACFs, these medicines are often liquids, inhalers, or topical creams (Ministry of Health, 2011c).

reconcile non-medicinal information from the paper charts into the new electronic charts, such as allergies, medical conditions, room number information, and GP allocation. All prescribers are contacted with relevant implementation dates, System *X* user resources, and an online video playlist of prescriber training in use of System *X*. All prescribers new to System *X* are offered one-on-one training with a System *X* employee. All medicines exported into System *X* must be 'Approved' by a prescriber prior to being available to RACF staff to be administered.

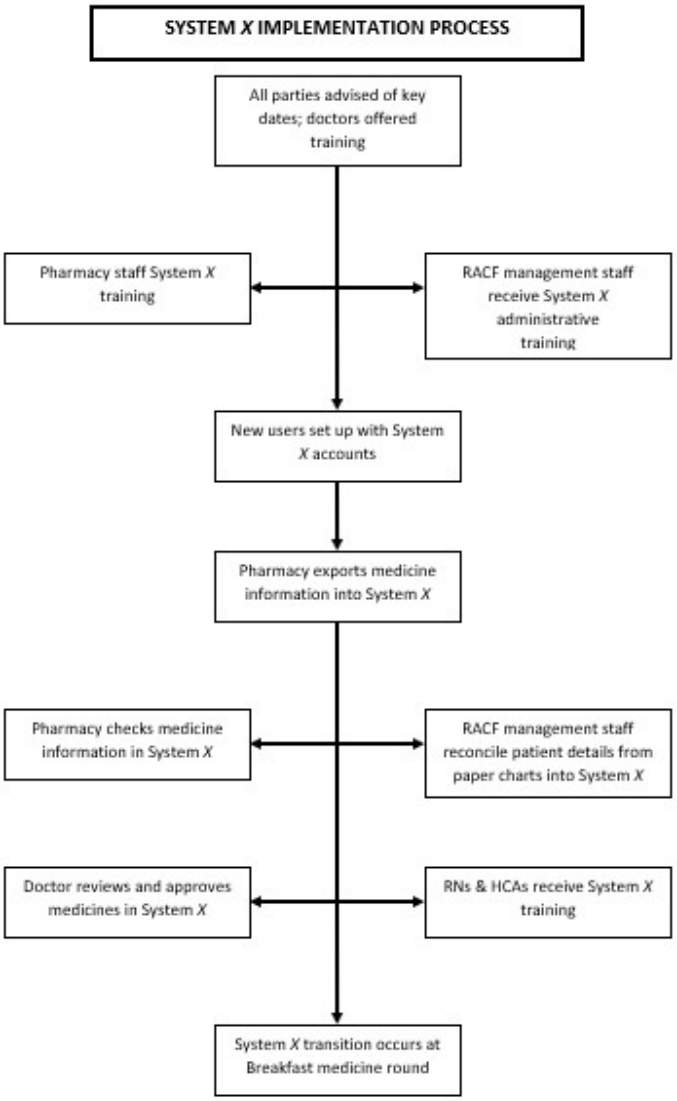

Figure 3: Process of System X implementation into RACFs

Two to three clinical training sessions are undertaken onsite at the RACF; all medication-competent staff members working at the RACF at the time are encouraged by their management team to attend one of the sessions. Generally, the only medication competent staff members who miss training are those who were absent from work for due to sickness or vacation; the RACF clinical management team are provided with an online video playlist as well as a competency checklist in order to cover the material with the staff member(s) who missed the training. Each training session is held by a System *X* employee and focuses on the day-to-day activities for medication-competent staff in System *X*, such as how to sign off a medication on time as having been administered or not, how to sign off overdue medications, how to record PRN medications' effectiveness, and more. RACFs often transition to

System *X* the day immediately following the trainings, though this can be delayed for a matter of weeks depending on whether or not the electronic charts are up-to-date and 'Approved' by the prescriber(s).

2.13. Conclusions

HIT is seen as a foremost strategy in increasing patient safety in healthcare systems around the world, and research has demonstrated that EMM has improved medication safety in acute hospital settings. Numerous benefits to use of EMM have been found, including decreased missed medications, better time and date documentation, a reduction in double-signing errors, improved legibility and communication, and more. With elderly people living longer and requiring increasingly complex medical care, these findings should be reflected in EMM use in RACFs. When evaluating the efficacy of new EMM products, research is more often conducted in acute levels of care (Fuller et al., 2018), and the focus is more often on errors in the prescribing and dispensing of medications rather than errors in administration (Guo et al., 2011). Care staff in RACFs are the last barrier before a medication is administered to a patient (Berdot et al., 2016; Guo et al., 2011). Administration errors are equally crucial to measure, especially considering the majority of preventable adverse drug events (ADEs) occur in the prescribing or administering stage of the medication management process (P. Aspden et al., 2007; Guo et al., 2011). As indicated earlier, the levels in training varies among medicine administrators in RACFs, and as the need for and complexity of aged care increases, so does the necessity for safe, effective, and reliable medication administration processes. As past research has demonstrated negative consequences alongside the benefits, including risks in transition of care and lack of familiarity or comfort with technology, it is imperative to empirically note if the EMM systems in place in New Zealand RACFs are actively affecting the rate of medication administration errors occurring. Further to this, it is crucial that any unprecedented medication administration errors have not been introduced with the implementation of a new system.

2.14. Primary Objective of the Research

The primary objective of the research was to utilise retrospective MAE data to assess any change in MAE rate following introduction of an EMM into aged care facilities. This is valuable

for evaluation of existing EMM programs, extrapolating their use in other areas of the health care sector, and creating a baseline for further research.

The primary outcomes of interest are any reduction in MAE rate across an RACF organisation, any reduction in MAE rate within specific levels of care, and any statistical difference in types of medication administration error occurring. The primary outcome measure was the number of medication administration error occurrences prior to System *X* implementation and the number of occurrences following implementation.

2.15. Specific Study Aims

The key aim of the research was to gauge any measure of statistically significant reduction in MAE rate after the implementation of an EMM system into New Zealand RACFs. Parallel aims of the research included exploring any change in MAE types before and after system implementation as well as any error types eliminated or introduced following the implementation of the intervention.

2.16. Research Questions & Hypothesis

2.16.1. Research Questions

Has use of an EMM system in New Zealand RACFs reduced MAE rate when compared to the paper-based system used prior to EMM implementation?

Furthermore, has implementation of an EMM system in RACFs reduced MAE rate within any particular care level?

Lastly, has implementation of an EMM system in RACFs reduced or eliminated any particular classification of MAE?

2.16.2. Study Hypotheses

It is expected that EMM systems have reduced the rate of medication administration errors in RACFs in New Zealand. The goal of this research is to validate a reduction in MAErate in RACFs after transitioning to an EMM system by measuring the difference between the paper-based system's MAE rate and System *X* MAE rate. This was done by a) examining the overall change in MAE rate before and after implementation of System *X*, b) identifying any reduction in

MAE rate within specific levels of care, and c) investigating any change in occurrence of types of medication administration errors.

3. METHODS

This chapter describes the approach taken by the primary investigator to examine and quantify difference in medication administration error rate before and after implementation of the intervention, a New Zealand-based EMM system. For reasons of confidentiality, a moniker "System *X*" was used for the EMM system examined and was used to refer to the intervention throughout the paper.

3.1. Study Design & Overview

A before-and-after retrospective longitudinal study design was employed to quantitatively analyse changes in medication administration error rate following implementation of New Zealand-based EMM system, System *X.* Retrospective data were considered most suitable for this project as a means of analysing a larger period of EMM use than would be feasible with direct observation. Furthermore, as the intervention was already implemented at the participating organisations, retrospective pre-implementation data were a necessity. Pre-System *X* implementation error data were treated as the control for the study as error data from a facility which has not implemented System *X* were not available to the primary investigator and would further account for characteristics of the organisation where System *X* was implemented.

3.2. Participants & Recruitment

RACFs were the units of study, and level of care was the unit of analysis as explained in the following sections. The clinical quality coordinators for three RACF organisations were approached via email by the primary investigator early on in the project. One organisation, consisting of 31 RACFs, advised they could not provide data as they had recently employed a new staff member to conduct routine research on their data. The other two organisations, making up a total of 49 RACFs, agreed to participate by supplying the relevant data subject to any ethics approval granted by the University of Canterbury Human Ethics Committee and any required approval from their respective ethics committees. All provisionally participating organisations were informed they would receive the results of the research upon completion of the thesis and prior to any subsequent publication. They were also advised that any data received would be securely stored, password-protected, viewable only by members of the research team, and disposed

of in a safe and timely fashion in accordance with the rules and regulations of the University of Canterbury.

RACFs were selected based on the following inclusion criteria, primarily on the basis of their use and recent implementation of the intervention System *X* in their respective facilities. All potential participants selected had a minimum of 14 months of System *X* use. Fourteen months was selected as the minimum period of post-intervention data to allow for a full calendar year of usable post-implementation data; the 14-month minimum period therefore included a two-month period immediately following System *X* implementation in each respective facility to be removed from the dataset. This two-month period is to minimise the effect of staff adjusting to a new system on reported incidents and was therefore excluded from the dataset; it was assumed that the RACF staff, as new users of System *X,* would need two months to become acquainted with the new system.

3.3. Data Acquisition

Two RACF organisations with 49 RACFs were initially drafted for the project but did not provide data. A separate organisation which met the inclusion criteria for the study was then approached and responded positively to providing data. The participating organization has seven RACFs within the same urban region of New Zealand. Data were provided in late January 2019 consisting of error counts stratified by error type for each month of 2016, 2017, and 2018.

For each RACF, the variable "occupied bed rate" was calculated as the average daily number of patients in each RACF multiplied by number of days in the month, were also supplied for each month from January 2016 to December 2018. In compliance with anonymity and confidentiality, the name of the RACF organisation, the location of the RACFs, and the name of the EMM system were not disclosed in this study.

Data consisted of those collected from seven RACFs covering three levels of residential care: dementia; rest home; and intellectual disability. The RACFs were divided into nine mutually exclusive groups for analysis to correspond with RACFs accommodating more than one care level (e.g. distinct dementia and rest home-level areas within the same facility). One RACF was subsetted into three care levels; this is how the organisation collected information about this RACF, so this pattern was maintained in the study. The separate groups are considered the participants of the study and are hereafter referred to as individual RACFs in this paper to measure care level accurately. The nine groups comprised the participants of the study.

Each group provided one care level to residents: dementia; rest home; or intellectual disability. One RACF provided intellectual disability care; while this is not considered to be aged care specific, the data were included as the practice around medication management in such facilities, where residential, is the same as for aged care specific facilities.

3.4. Implementation of Intervention at Participating Organisation

Implementation of System *X* took between four and six weeks per RACF, with official transition dates staggered over four months from July to October 2017. The implementation period involved the RACFs' contracted pharmacy exporting the dose pack information from their dispensary system into System *X*. The pharmacy was trained by a System *X* staff member in how to export this information. The exported information created the electronic charts in System *X*. The pharmacists then checked the electronic charts against the information in their dispensary system, adding any missing medicine information. A training was conducted with the senior RNs of the RACFs by a System *X* staff member (the primary investigator of this research) to train them in how to reconcile non-medicinal information from the paper charts into the new electronic charts; the clinical manager of the group of RACFs was already experienced with System *X* and undertook the bulk of this administrative work for the RACFs involved in this study. All prescribers new to System *X* were offered one-on-one training with a System *X* employee, though none took up the offer; the majority of GPs involved with care of residents at the RACFs involved in this study were existing System *X* users at the time of implementation. All GPs were emailed an electronic copy of the most recent iteration of the System *X* prescribers' manual in addition to other resources specifically targeting implementation activities (such as approving medications exported by a pharmacy). A video playlist of prescriber training in System *X* was also provided to all GPs involved in System *X* implementation at the RACFs, though it is unclear how many of the GPs used this training method. No issues with GP uptake with or barriers to the product's implementation were reported.

Three clinical training sessions were undertaken at each facility; two groups of two facilities shared three sessions between their staff due to immediate proximity. Each RACF staff member working at the facilities at the time who was qualified to administer medication to residents was required by their management team to attend. The only staff members who missed training were those who were absent from work for an external reason (e.g. sickness or holiday) or had attended a System *X* training session at a previous place of employment and were therefore

familiar with the system. Each training session was held by the same System *X* employee, the primary investigator. The training session focused on the general, day-to-day activities for medication-competent staff in System *X*, such as how to sign off a medication on time as Given or Not Given, how to sign off overdue medications, how to record PRN medications' effectiveness, and other similar functions. All facilities transitioned to System *X* the day immediately following the respective trainings. The primary investigator was onsite at the facilities for the first two drug rounds of each facility's first day using the system.

All RACFs used voluntary incident reporting to record MAEs before and after System *X* implementation. Medication errors were reported on structured incident forms by the RACF staff member(s) involved in the incident or other RACF staff members who witnessed it. Incident forms were collected by the senior clinical manager at each RACF and then provided to the clinical quality manager of the RACF organisation. The clinical quality manager and senior clinical staff assigned an error type to each incident; the clinical quality manager then collated all the incidents by month of occurrence and error type into a spreadsheet for each RACF. These spreadsheets were provided by the clinical quality manager for the years 2016, 2017, and 2018.

3.5. Data Preprocessing

Data were reviewed and manually compiled into password-protected comma-separated value file format. As explained in Section 3.2, data from the month of System *X* implementation and the two months immediately following the month of implementation two-month period were excluded from the dataset in order to minimise the effect of staff adjusting to a new system on reported incidents.

As noted in Section 3.4, error types had already been allocated to each incident occurrence by senior clinical staff at the participating RACF organisation. Each incident was assigned one of the following categories:

Error Type	**Description**
Pharmacy error	Error occurring at the pharmacy during the dispensing process
Wrong resident	Medication given to or attempted to be given to the wrong person
Wrong dose	Administration of the incorrect dose of medication
Wrong time	Administration of medication at the incorrect time
Wrong day	Administration of medication on the incorrect day
Pill found	Medication found on floor of patient's room following administration
Not given	Omitted dose of medication
Med reaction	Reaction to administered dose medication

Other	Any medication administration-related incident which does not fall into the above categories

Table 1: MAE error type descriptions

No further detail was available about each incident. One error category, Pharmacy Error, was excluded from the compiled dataset as it was considered to not be a medication administration error as it related to dispensing by pharmacy staff rather than administration by RACF staff.

Data used in the research were collected and provided by the RACF organisation; medication error information is routinely collected by residential aged care facilities as part of their quality improvement policies and procedures. Medication administration error incidents were reported by the care staff member(s) involved in the incident or by other care staff members who witnessed the incident.

Data were imported into R v3.5.3 (R Core Team, 2019). As explained in Section 3.3, the RACFs were divided into nine separate groups for analysis to correspond with the level of care provided. The RACFs were assigned a name based on the care level: D1, D2, D3, D4, D5, D6, R1, R2, and I1 in which 'D' corresponds with dementia level care, 'R' represents rest home level care, and 'I' indicates intellectual disability level care. The data file consisted of the following information (also displayed in *Table 3*):

Variable	**Description**
RACF code	The RACF codes, *e.g.* D1, D2, R1, *etc.*
RACF care level	The care level of the specified RACF, *e.g.* Dementia, Rest Home, *etc.*
Actual month	The month of the year, *e.g.* January 2016, July 2017, December 2018, *etc.*
Relative month	The month relative to the specified RACF's implementation of the intervention, *e.g.* -3 for 3 months prior to implementation or 3 for 3 months post-implementation
Number of MAEs	The number of medication administration errors that occurred at that RACF during the specified month
Before/After	Whether the specified month occurred before or after System *X* implementation at the specified RACF
OBR	The specified RACF's occupied bed rate for the specified month
Bed capacity	The specified RACF's overall bed capacity[10].

Table 2: Data file variables and descriptions

[10]Bed capacity, or the total number of residents an RACF can care for, is measured by care level and confirmed in mandatory audits (Ministry of Health, 2013b). When an RACF intends to add bed capacity to the facility, this must be confirmed in an audit by a designated auditing agency (Ministry of Health, 2013b). Both surveillance and certification audits contain the audit-certified bed capacity of the RACF under audit.

There was a significant outlier in the seventh month relative to I1's implementation of System *X*. This was excluded from the dataset as a highly influential observation possibly recorded in error and is further discussed in Chapter 5.

3.6. Statistical Analysis

This study did not involve comparisons between RACFs using EMM systems and those not using EMM, but rather compared the same RACFs at two time points (before and after EMM implementation); the null hypothesis for this study was that the MAE rates would be similar or identical before and after EMM implementation. This was assessed for statistical significance so that the alternative hypothesis, "EMM use leads to a reduction in MAE rate at RACFs", could be accepted or rejected. To test whether there was any effect within specific care levels, sub-analysis was undertaken to assess for any significant effects with System *X* use in each care level and within only the aged care data (Dementia and Rest Home care combined) to verify if there was a care level specific effect. The second part of the analysis examined any difference in total error occurrence within the seven distinct error categories before and after System *X* implementation; there is no overlap in the error categories, or no errors which have multiple error categories assigned. *p*-values of less than 0.05 were considered statistically significant.

Firstly, the difference in MAE totals occurring before and after System *X* implementation were measured. A Poisson regression model was used for analysis due to the use of count data. The dispersion index for the entire dataset was measured to determine if a Poisson distribution was appropriate. The dispersion index is a variance to mean ratio, or VMR, which is used for Poisson distributions to select the appropriate model. Where the VMR < 1, there is underdispersion in the data; where the VMR > 1, the data are overdispersed, which is to say the data have greater variability than would be expected for a Poisson model. Following the dispersion test in R, implementing Cameron & Trivedi's Test for Overdispersion, the data proved to be overdispersed with a dispersion index of 3.7, well over 1 (Berk & MacDonald, 2008). Due to overdispersion of the data, a generalised regression model (GLM) was used to examine the change in the rate of medication administration errors over time.

A MAE rate was not readily available in the dataset since the total number of opportunities for medication administration errors was not available for the pre-EMM data. Assuming the occupancy rates were constant, MAE rates were calculated by dividing the sum of medication

administration errors with the product of monthly OBR for each RACF and respective maximum bed capacity of the RACF.

The MAE rates were plotted over time using months relative to the intervention's implementation in each RACF. Plotting over time required adjustment as the participating RACFs implemented System *X* at different times, staggered over four months. Therefore, rather than plotting the data over actual months, such as July 2017, the data were plotted over months relative to each RACF's respective implementation of System *X*.

A GLM in the Gaussian family was then fitted to examine the relationship between errors before and after System *X* implementation with the following formula:

$$y_i = \beta_0 + \beta_1 x_i$$

The variable x was assigned a binary value of either 0 or 1, representing either "before" or "after" implementation respectively. Estimates of β_0 (representing the constant "before" MAE rate) and β_1 (representing the expected change in MAE rate due to implementation) along with 95% confidence intervals were obtained from the model. The sub-analysis by care level was also conducted using this model.

Secondly, before-and-after error type totals where each of the distinct seven error types was analysed for statistically significant differences before and after System *X* implementation. Data were manually compiled into a separate file and categorised by error types rather than number of occurrences per month. The dataset was then imported into R v3.5.3 for analysis (R Core Team, 2019). The number of data samples was much smaller when stratified into the seven different error classes; with the number of data samples reduced so much over the same 36-month period, it may have lent too much predictive power to a regression model where the month is used as a regression variable. The Mann-Whitney *U* test was employed as a simple comparative test to gauge any relationship between the pre- and post-intervention error type counts.

3.7. Ethics

Ethics approval was sought from the University of Canterbury Human Ethics Committee. The committee reviewed the application and advised that no ethical approval is required for this project as the data to be used were secondary and anonymous (see Appendix 1 for details). Any processes for ethics approval required by participating organisations was abided; in every case, this involved the primary investigator supplying a brief letter detailing the purpose of the research

and what would be required of participating organisations; in addition, the research proposal was provided and any subsequent questions answered.

Ethical points to consider included ensuring all participating organisations understood the purpose the use of their respective data would be used for as well as the security of the storage of the raw data. As all data provided were anonymised in nature, no personal data were disclosed. All provisionally participating organisations were assured the data would be utilised with respect. Furthermore, no identifying information of an individual, facility or organisation were disclosed in the project to protect anonymity. The intervention involved has been anonymised in the project to further protect anonymity of the participating organisations.

4. RESULTS

4.1. Descriptive Statistics

The participating organisation provided data for nine RACFs covering three care levels: dementia; rest home; and intellectual disability. The total bed capacity for the participating RACFs was 349. As displayed in *Table 3*, D1, D5, and I1 each had a bed capacity of 40. R1 had the largest bed capacity of the groups at 54; D3 had a smallest capacity at 14. Dementia level care made up six of the nine RACFs and had the highest collective capacity at 203. Two of the RACFs were rest home level care with a collective capacity of 106. The remaining RACF had an intellectual disability care level with a capacity of 40.

Care Level	Care Facility	Bed Capacity	Errors Before	Errors After	Difference	% Change Relative to Baseline
Dementia	D1	40	10	7	**-3**	-30
	D2	27	1	1	**0**	0
	D3	14	5	4	**-1**	-20
	D4	41	23	12	**-11**	-47.8
	D5	40	50	27	**-23**	-46
	D6	41	10	12	**2**	20
Rest Home	R1	54	19	11	**-8**	-42.1
	R2	52	24	10	**-14**	-58.3
Intellectual	I1	40	17	41	**24**	141.2
Total	-	349	159	125	**-34**	-21.4

Table 3: MAE data before and after implementation

Also visible in *Table 3*, medication administration errors reduced following System *X* implementation in all but three of the nine RACFs; two of the RACFs saw an increase in errors, and one RACF saw no change.

Similarly, as exhibited in *Table 4*, MAE types reduced across all categories apart from two: Medication – Reaction and Other.

Error Type	**Before**	**After**	**Difference**	**% Change Relative to Baseline**
Wrong resident	16	9	**-7**	-43.8
Wrong dose	14	7	**-7**	-50
Wrong time	13	2	**-11**	-84.6
Wrong day	3	1	**-2**	-66.7
Pill found	25	23	**-2**	-8
Not given	52	39	**-13**	-25
Med reaction	0	1	**1**	100
Other	36	43	**7**	19.4

Table 4: MAE data stratified by error type

4.2. Effect of System X *Implementation on Medication Administration Error Rate*

To briefly reiterate, the MAE rate was calculated using the total monthly number of medication administration errors, each RACF's monthly OBR, and each facility's maximum bed capacity. Months were represented by the months relative to each RACF's month of implementation to account for the staggered implementation period across the organisation. For example, the value of -6 would represent six months prior to the implementation month; a positive value of 4 would represent four months following the implementation month.

MAE rate before and after EMM implementation (all RACFs)

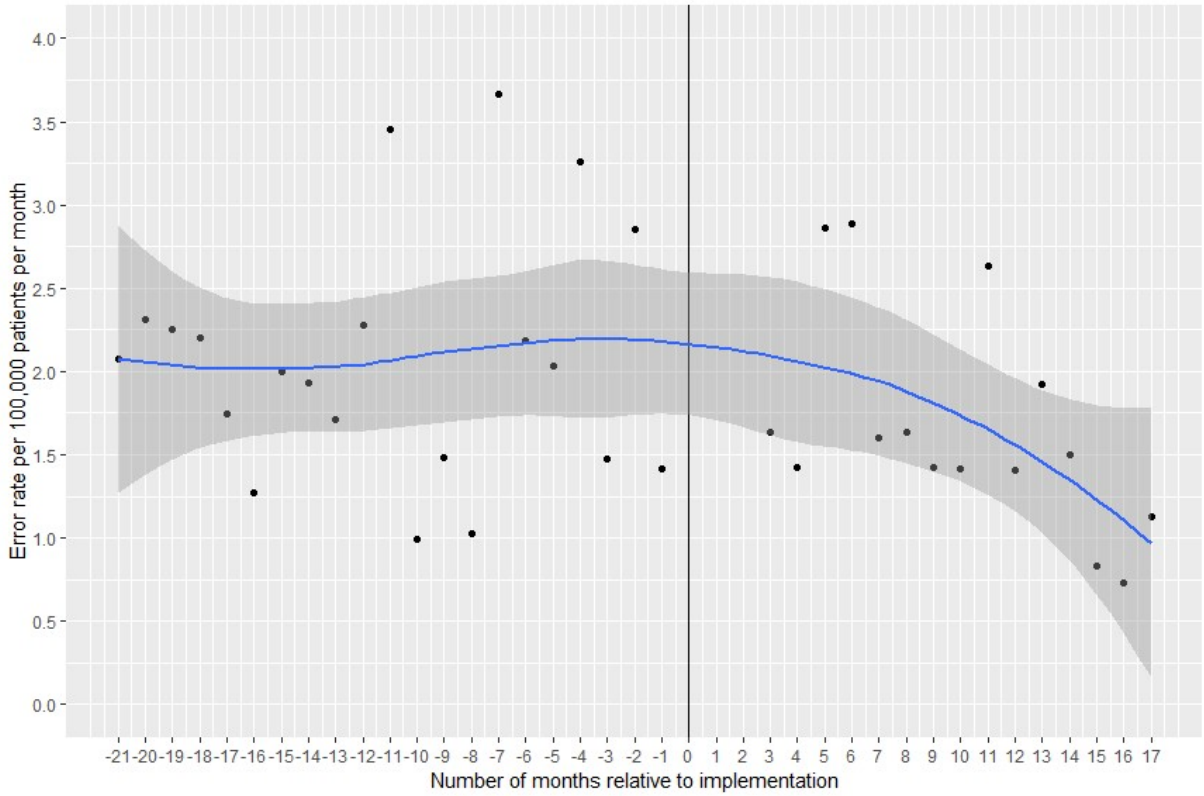

Figure 4: Error rate per 100,000 patients per month relative to implementation with Loess curve

Running a Gaussian regression on the full dataset predicted that use of System *X* in RACFs would reduce the error rate from 2.08 per relative month to 1.67 per relative month (absolute reduction, or AR: 0.41 [-0.87 – 0.06] errors per month, relative reduction: 19.7% in error rate; *p*-value*:* 0.098) as per *Figure 4*. Though demonstrating a downward trend in medication administration errors, this displayed no statistically significant reduction in MAE rate following System *X* implementation.

MAE rate before and after EMM implementation (Aged Care RACFs)

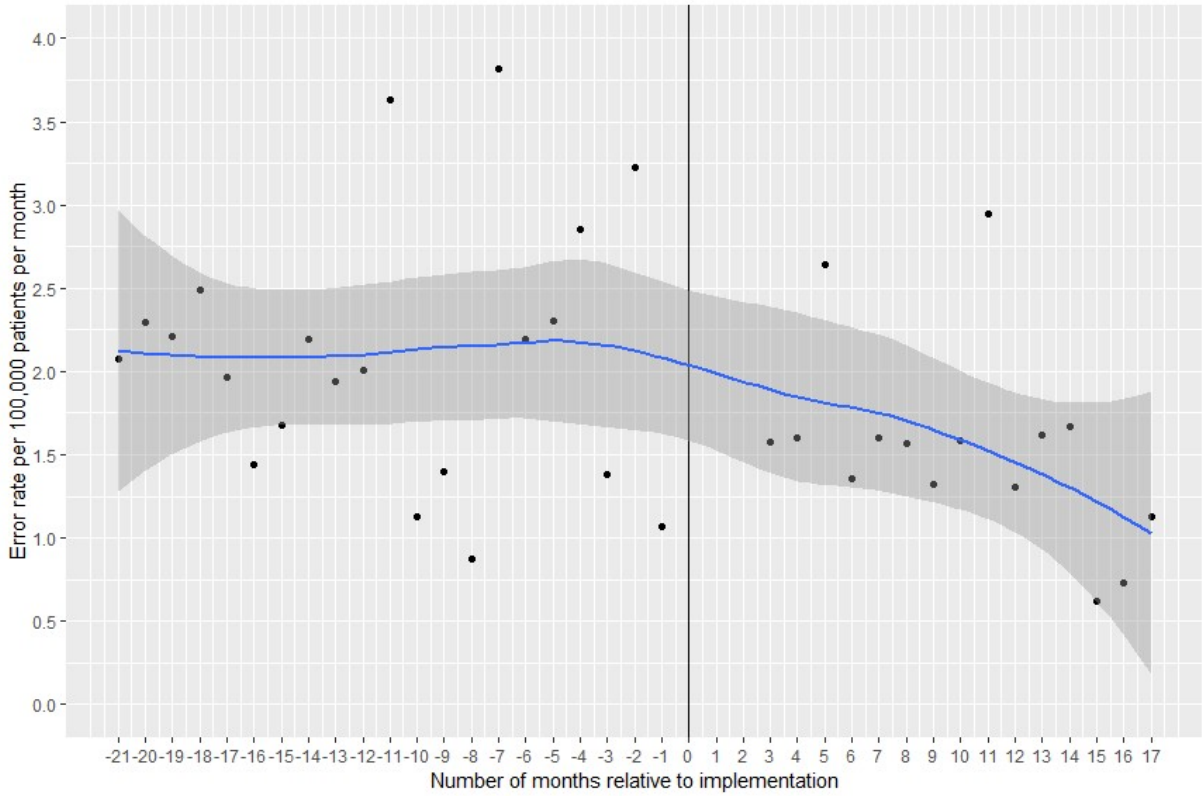

Figure 5: Error rate per 100,000 patients per month relative to implementation with Loess curve - Aged care only (Dementia and Rest Home care)

To analyse care levels covering aged care only, data from only Dementia and Rest Home care level RACFs were used, for a total of eight RACF groups as illustrated in *Figure 5*. This as a result predicted a reduction from 2.10 MAE per month to 1.55 per month (AR: 0.55, relative reduction: 21.2%; *p*-value*:* 0.03), indicating a statistically significant reduction in medication administration error rate following System *X* adoption.

The Durbin-Watson test was also performed on the residuals for each analysis to check for autocorrelation, with the resulting scores of 1.83 (*p*-value: 0.49), 2.08 (*p*-value: 0.94) and 2.39 (*p*-value: 0.85) respectively. Autocorrelation is not strongly indicated per the Durbin-Watson test.

4.2.1. Sub-analysis by Care Level

As described in the Methods chapter, the effect of System *X* on MAE rate was assessed by individual care level: dementia; rest home; and intellectual disability.

MAE rate before and after EMM implementation (Dementia)

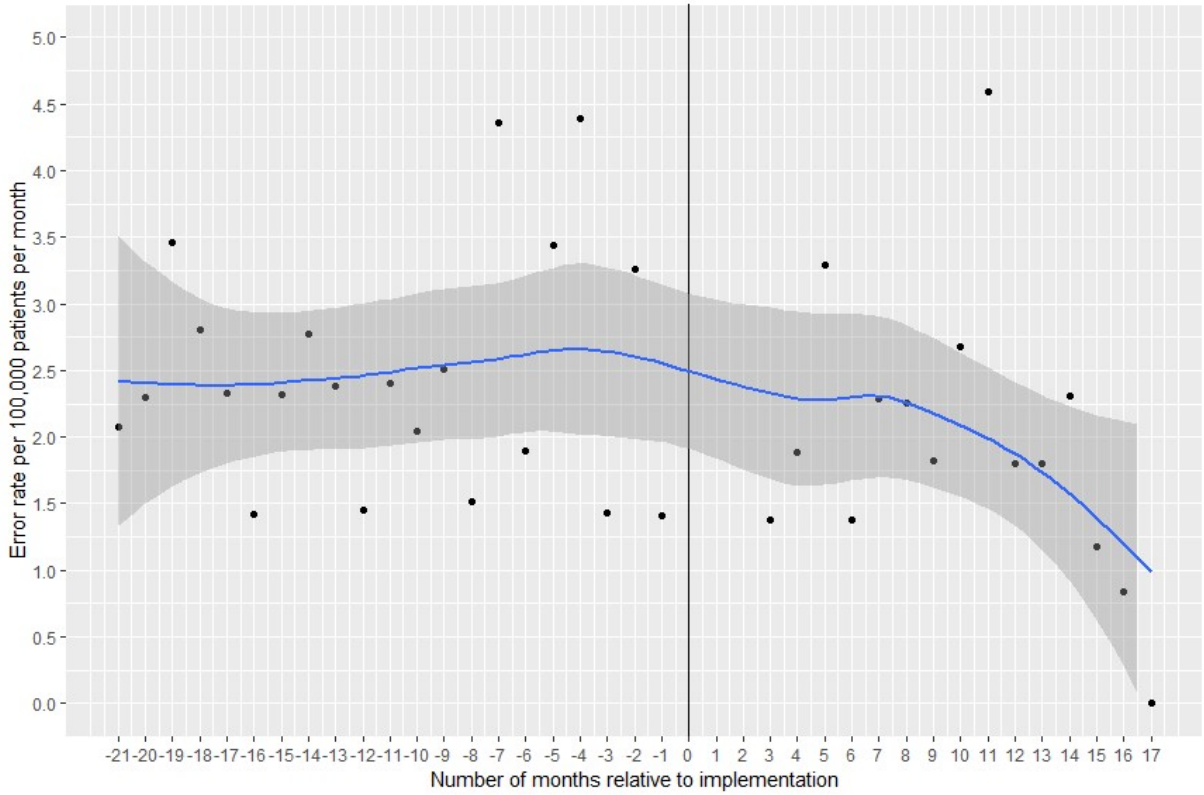

Figure 6: Error rate per 100,000 patients per month relative to implementation with Loess curve – Dementia care

Analysis of Dementia care data predicted a reduction in MAE rate from 2.48 per month to 1.97 per month (AR: 0.51 errors per month, relative reduction: 20.6% in error rate; *p*-value*:* 0.13).

MAE rate before and after EMM implementation (Rest Home)

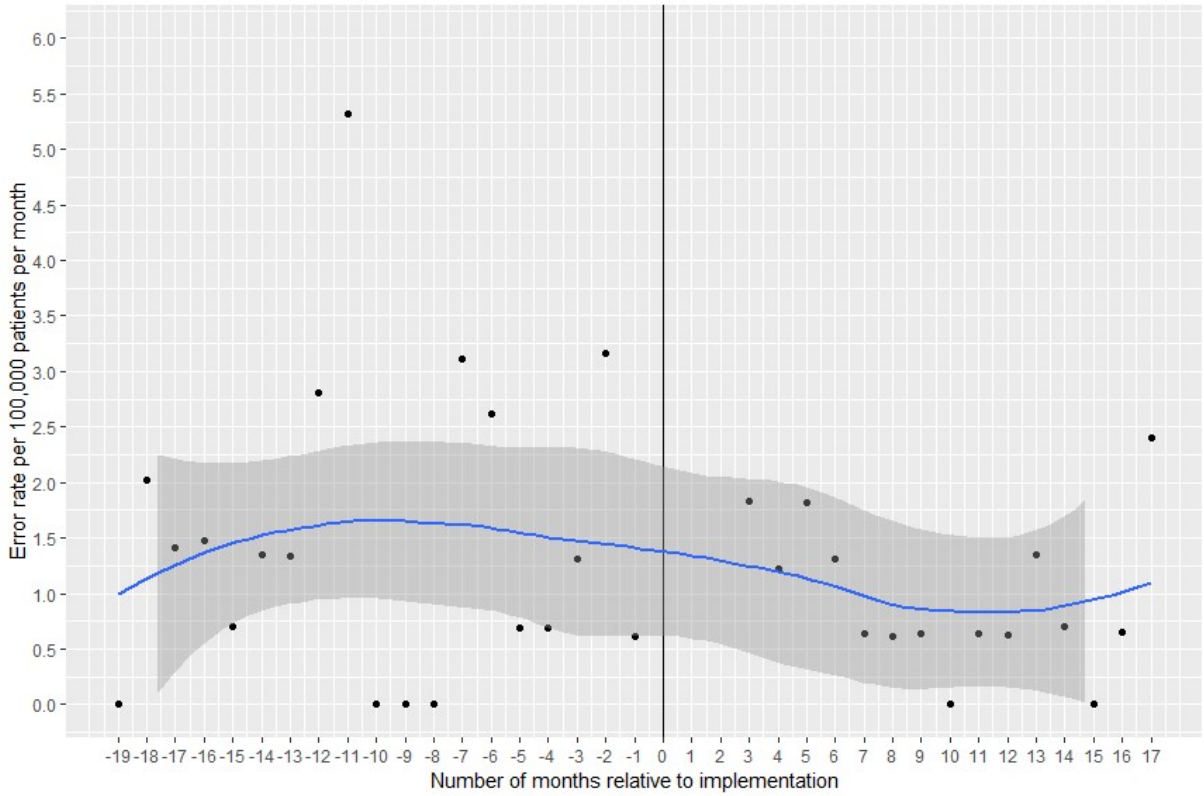

Figure 7: Error rate per month relative to implementation with Loess curve - Rest Home

Similar predictions were found within the Rest Home care data, with a reduction in MAE rate from 1.51 per month to 0.96 per month (AR: 0.96 errors per month, relative reduction: 36.4% in error rate; *p*-value: 0.18).

MAE rate before and after EMM implementation (Intellectual Disability)

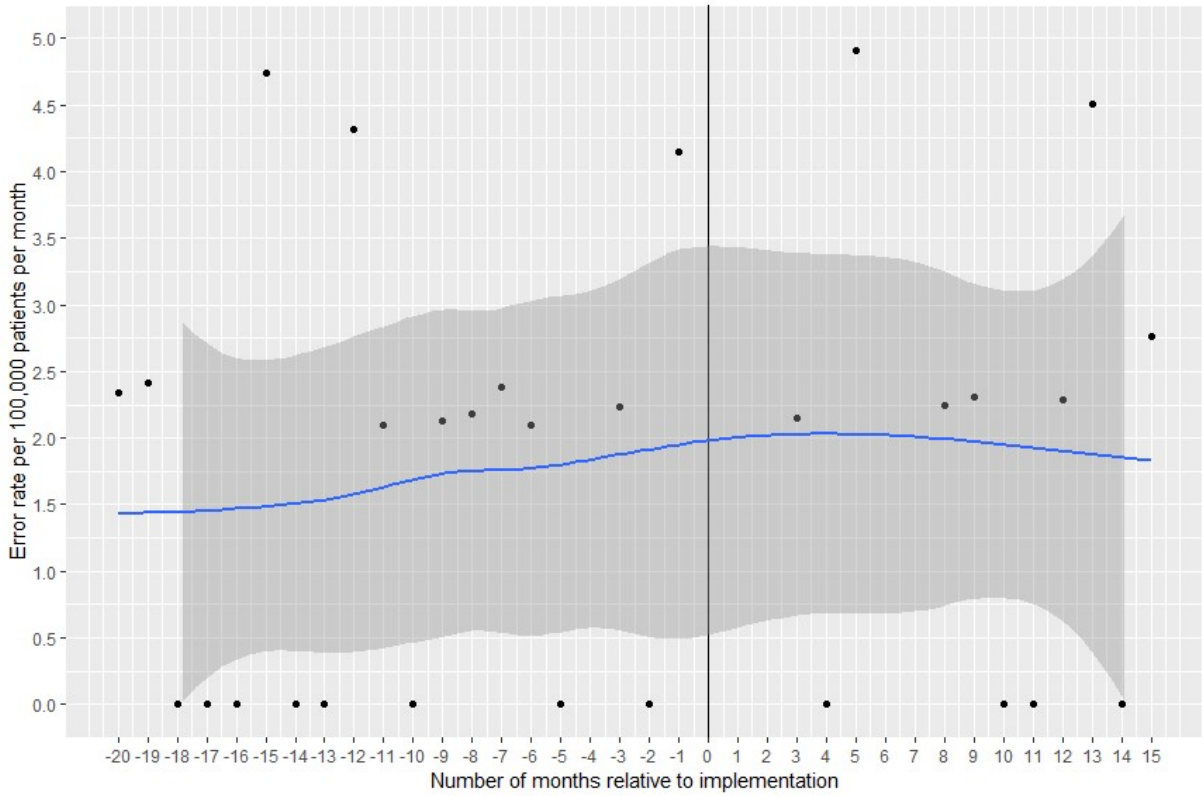

Figure 8: Error rate per month relative to implementation with Loess curve - Intellectual Disability

Regression analysis was lastly conducted on the Intellectual Disability dataset, predicting an increase in MAE rate post implementation from 1.87 per month to 3.02 per month *(p*-value*:* 0.29*)*.

Dataset	Beta-coefficient	95% Confidence Interval	*p*-value
Total Error Rate	-0.41	-0.87 – 0.06	0.098
Aged Care	-0.55	-1.03 – -0.08	0.0295*
Dementia Care	-0.51	-1.15 – 0.13	0.13
Rest Home Care	-0.55	-1.32 – 0.22	0.176
Intellectual Disability	1.15	-0.95 – 3.26	0.29

*Table 5: Summary of GLM analysis results per dataset. * = statistically significant*

As shown in *Table* 5, for Aged Care, the beta-coefficient of -0.55 suggests that with System *X* use, for each subsequent year, there would be 6.6 fewer errors than if System *X* were not used (p=0.0295). The 95% confidence interval for this beta-coefficient does not traverse the null value of 0 (which would indicate no change); therefore, one can say with 95% certainty that the true effect of System *X* implementation in Aged Care is a reduction in monthly MAE rate between -1.03 and -0.08 per month.

4.3. Effect of System X *Implementation on Medication Administration Error Type*

As noted in the Methods chapter, all medication administration errors were classed into various categories by the RACF organisation when reported: Wrong Resident, Wrong Dose, Wrong Time, Wrong Day, Pill Found on Floor, Not Given, Medication Reaction, and Other. The 'Other' category represented all errors which could not be classed into the other available categories. All data samples were assigned one distinct error classification, so there was no overlap between the error categories.

As exhibited in *Figure 9*, the total number of MAE types before and after System *X* implementation across all care levels demonstrates an overall reduction in all MAE types except for the 'Med Reaction' and 'Other' categories.

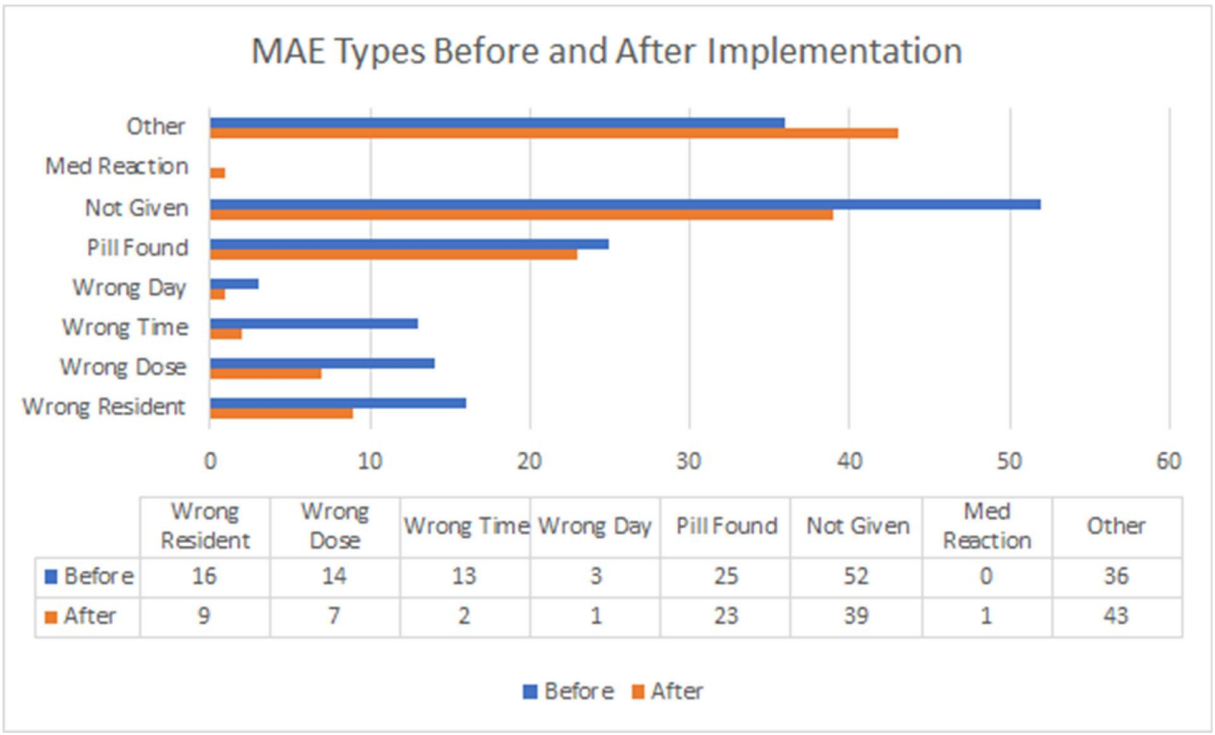

Figure 9: MAE type occurrences before and after System X implementation

The Mann-Whitney *U* test was run for each MAE category in the R program using the Wilcoxon rank sum test with continuity correction to measure the relationships between pre-System *X* implementation MAE type occurrences and post-implementation occurrences.

Error Type	**Total Errors**	**Change in Errors**	***p*-value**
Wrong resident	25	Reduction	0.75
Wrong dose	21	Reduction	0.62
Wrong time	15	Reduction	0.03*
Wrong day	4	Reduction	0.76
Pill found	48	Reduction	0.45
Not given	91	Reduction	0.70
Med reaction	1	Increase	0.24
Other	79	Increase	0.68

*Table 6: Summary of error type and significance. * = statistically significant*

As displayed in *Table 6*, only the Wrong Time error displayed a statistically significant reduction in error occurrence within a confidence interval of 95%, in which case the significance threshold is $p < 0.05$. No other statistically significant change in MAE error type occurrence was found.

5. DISCUSSION

This chapter aims to discuss the findings from Chapter Four within the context of the research questions stated in Chapter Two and to assess the utility of EMM systems in other areas of New Zealand's health care sector, as understanding the effects EMM solutions have on medication administration errors in RACFs impacts the extrapolation of their use to other areas of the healthcare sector, such as district nursing programs and home care. Furthermore, such systems are relatively young in New Zealand and continue to evolve; evaluating how solutions like System *X* impact medication safety is a crucial step in ensuring products improve consistently with user expectations.

This chapter is structured to first discuss the findings from the study as summarised in Chapter Four in the framework of the study's research questions as well as various literature discussed throughout Chapter Two. Following the review within the residential care context, the chapter then discusses the potential utility of EMM systems in other parts of the New Zealand health system.

5.1. Key Findings

MAE data before and after the intervention's implementation were provided by an RACF organisation in an urban area of New Zealand. The primary research question queried whether or not the rate of medication administration errors reduced at the participating RACF organisation following the implementation of New Zealand-based EMM solution, System *X*; it was expected that the MAE rate would decrease. It was further queried whether or not the MAE rate diminished following the system's implementation within any specific level of residential care available in the data. The secondary research question sought to investigate reduction or elimination of any particular MAE type following System *X* implementation, with the expectation that some classifications would reduce.

Analysis took place in two parts: Gaussian regression of the MAE rate before and after implementation and, using a Mann-Whitney *U* test, examining any statistically significant difference in occurrence of different MAE types. While raw data demonstrated an overall reduction in error, the reduction in error rate was significant only for the combined aged care-specific care levels (Dementia and Rest Home level care). No other rate reductions were significant, though a downward trend was seen in all care levels apart from Intellectual Disability.

Among the MAE types, no type category was eliminated, and only the Wrong Time error saw statistically significant reduction.

5.2. Limitations

5.2.1. Limitations of Data Acquired

There are limitations to the data utilised in this research. As a fundamental aspect of the study design involved using retrospectively collected data, access to data is entirely reliant on what can be provided by the participating organisations.

1. *Age of care staff member*

It would be prudent to include age of the care staff member(s) involved in each individual medication administration error as this has the potential to be relevant with regard to experience with or exposure to electronic devices integral to the processes of System *X*, like tablet computers. Confidence using these devices may affect one's confidence using System *X*. However, this information is not recorded in MAE incident forms.

2. *Role of care staff member*

It would be useful to know the employed role and duties of the care staff member(s) involved in each medication administration error as this more than likely will be related to their respective levels of healthcare-related education. Healthcare-related education and resultant qualifications may have an effect on the number and type of medication administration errors occurring.

3. *Other new systems and procedures*

Other new systems, procedures, and care responsibilities may have been introduced over the measured time period. Numerous simultaneous or subsequent changes may impact or overwhelm care staff.

4. *Reported data*

The data used in the research is entirely based on reported incidents. Incidents can be reported by the care staff member(s) involved in the incident or by other care staff members who witnessed the incident. The data therefore does not include unreported incidents.

5. *Near-misses*

As the data used in the research is entirely based on reported incidents, the data does not accommodate near-misses in medication administration, in which a care staff member almost commits a medication administration error, whether knowingly or unknowingly.

6. *Varying staff (and resulting varying training levels)*

The data used in the research were collected over a timeframe of three years. With a high nursing shortage in aged care facilities in New Zealand, it is likely that some staff left the employment of the involved organisations and some new staff began employment during this period of time (Lewis, 2018). Additionally, some care staff may have become medication-competent during this time, giving them the ability to administer medications where they previously had none. Resultantly, the participants are not necessarily consistently the same throughout the collection of data. Change of staff also implicates the training new staff or newly medication-competent staff receive in the use of System *X*; some may have received System *X* certified training, where others may not have.

7. *Total number of administrations pre-intervention*

The total number of administrations per month pre-System *X* implementation could only be calculated based on the average number of post-System *X* administrations given per occupied bed day in each care level. As a result, while the post-System *X* administration count is assumed to be accurate in terms of the number of opportunities for administration error, the pre-System *X* administration count would be an estimate. It would be preferable to use accurate values to create a rate rather than an estimate for more accurate results; however, acquiring the accurate count would involve counting total medication administrations over an 18-21-month period, or counting an average of 9.6 medication administrations on each of over 183,000 pieces of paper. Past medication administration records, or signing sheets, are not anonymised; counting medication administrations would resultantly require investigator access to identifying patient information. Furthermore, counting individual medication administrations could be error-prone and result in inaccurate count data. Considering the time constraints of the study, the total number of opportunities for medication administration error prior to System *X* implementation was not calculated. The opportunities for medication error prior to System *X* implementation were not estimated so as to maintain the accuracy and integrity of the data. Acquiring administration count

data is more accurate and less time-consuming using System *X*; this is arguably a benefit to employing an EMM system in place of a paper system.

8. Hybrid administration systems

The error counts provided include all errors to have occurred at the organisation's facilities from 2016, 2017, and 2018. However, while the aim of EMM systems like System *X* may be to eliminate as many paper medication records as possible, the paper-based system has not been eliminated in its entirety. As a result, some errors may have occurred using a paper-based medication administration system.

- Respite patients are only in residential care for short periods of time. If a respite patient's general practitioner (GP) is not a user of System *X*, he or she may opt not to become a user due to the temporary nature of the patient's stay. Resultantly, care staff at RACFs may be required to monitor both System *X* and a paper system. Paper administrations could not be included in the post-intervention data.
- Transfer of care can mean the necessity of a temporary paper-based system. When patients transfer between System *X* facilities, the chart can be transferred over the cloud-based system; in this case, once discharged from one System *X* facility, the chart and its respective MAR can effectively be moved to another System *X* facility if the transfer occurs within 28 days of discharge from the initial facility (the 28-day limit is a safety measure to ensure the chart is not out of date when transferred). Upon receipt of the transferred chart, the admitting doctor approves the medications already on the chart. However, patients do not always transfer between System *X* facilities and often transition between either paper-based RACFs or RACFs which employ the other EMM system used in New Zealand. Transfer to and from hospital also occurs. In these instances, charts can be paper-based for days to weeks at a time.
- GP uptake is also a necessity for a chart to be electronically based. If a patient's GP is not a System *X* user and does not wish to become one, the patient's chart will remain paper-based unless he or she wishes to change GPs. In this case, a facility employing an EMM system may have also some patients on paper charts. It should be noted that this has not occurred at the facilities involved in this research.

9. Control data

It would further have been useful to have control data from an RACF which has not implemented System *X* at all to accommodate for other factors which may influence MAE rate,

such as human error or other systems introduced to improve efficiencies; this would minimise threats to internal validity. Unfortunately, data from an RACF which has not implemented System *X* are unavailable to the primary investigator.

10. Reliance on retrospective data

There are limitations to retrospective data reported on paper, such as the accuracy of information reported and the potential for data on the form to be altered after the incident (Amina Tariq et al., 2012b).

11. Uneven before and after periods

The implementation of the intervention in this study was staggered over several months in 2017 to reduce burden on the organisation staff and prescribers involved in the system's implementation at more than one RACF. With the addition of the exclusion period for each facility (the month of implementation plus the two months immediately following the implementation month to minimise the effect of adapting to a new system on medication administration error occurrence, making a total of three months), the pre-intervention period is longer for each RACF group than the post-intervention period, thereby providing more opportunity for a higher error rate in the pre-implementation stage. In the data provided across all nine participating RACF groups, 172 months were examined in the 'before' period while only 125 months were examined in the 'after' period. This is the reason relative months were employed for the analysis.

5.2.2. Limitations of Analysis Method

A major limitation of the data used in the study was a lack of a total number of opportunities for error. For the MAE types, due to the small samples available, it was decided to use the non-parametric Mann-Whitney-Wilcoxon test, also known as the Mann-Whitney *U* test. Using this method of statistical analysis entails the assumption that the samples of data are independent of one another; in the case of this research, this assumes that one month's data samples do not rely on any of the other months' data. This may not be entirely realistic as the potential exists for staff members to be more vigilant in a month following a month wherein a large number of medication administration errors occurred, thus perhaps committing fewer errors in the month after. Furthermore, the number of medicine administrators onsite could vary from month to month with respect to holidays and sick leave. However, every statistical test will have their assumptions, and the assumptions to be considered in this case are mild.

5.3. Interpretation of Findings

The first expected outcome of the research was a reduction in the rate of medication administration errors following the implementation of an EMM system known in this study as System *X* in New Zealand RACFs. At first glance, the data demonstrates that this is indeed true; the overall count of medication administration errors dropped from 159 in the 'before' period to 125 in the 'after' period, a reduction of 21.4%. Regression analysis demonstrated that this was not a statistically significant difference within a 95% confidence interval. The resulting *p*-value was small, but the change was not significant; however, the relative reduction in error rate was 19.7%.

Stratifying the medication administration error counts into the care levels of the facilities they occurred within was necessary as the high-level care facilities mandate round-the-clock care while the low-level care residents require medical support but not constantly (J. Broad et al., 2011; Standards New Zealand, 2013). The levels of care analysed in the study covered the two broad levels of RACF care in New Zealand: hospital level care, or high-level care, and rest home care, or low-level care (Burrow et al., 2017; Fleming, 2010; Standards New Zealand, 2013). Dementia level care falls into the high-level care category whereas Rest Home level care falls into the low-level care category.

The third level of care, Intellectual Disability care, was provided by one facility of the group; while this level of care did not adhere strictly to the aged care aspect of the study, the data were included considering the medication management legislation in such facilities aligns with that of high-level residential aged care as another level of residential dependency (New Zealand Government, n.d.). Furthermore, the facility is residential in nature and met the study's requirement that medications be administered by care staff employed by the facility rather than assisting patients with their medications or medications being self-administered by the patients, which would be more similar to an assisted living home (Stefanacci & Haimowitz, 2012).

However, due to the Intellectual Disability care level's lack of reliance on aged care, the Dementia and Rest Home cohorts were further analysed together as an Aged Care cohort, completely excluding the Intellectual Disability data (Watchman & Janicki, 2017). The Aged Care cohort's MAE rate reduced significantly and predicted a relative reduction of 21.2%

When analysed individually, the Dementia and Rest Home care levels demonstrated an overall reduction in the raw counts of medication administrations, reducing from 99 to 63 errors and 43 to 21 errors respectively. The Intellectual Disability group, however, showed an increase

in raw error count, increasing from 17 to 41. While none of these changes were individually proven to be statistically significant, the higher reduction in the Rest Home category when compared to that of the higher level of care in Dementia can be considered reasonably logical. With a higher level of care, it is likely that the Dementia patients require more medical attention than those in the Rest Home level (Szczepura et al., 2011); furthermore, it is likely that the Dementia patients require more medications than their Rest Home counterparts, providing care staff with more opportunities for medication administration error than they would have in the Rest Home (Szczepura et al., 2011).

Unlike the other two care levels, the Intellectual Disability cohort had a boost in medication administration error count following System *X* implementation, increasing from 17 to 41 errors. This 141.2% jump is in part due to a single month containing 25 medication administration errors, the largest count of any other month for any care level. This data sample was the outlier excluded from the analysis as it was a highly influential observation. Indeed, no other care level had error quantities in the double digits. As the data were collected and initially recorded by the participating RACF organisation, this may have been recorded in error; however, as the Intellectual Disability group also had the second highest error count at 7, it is not unreasonable to assume there may have been a month with an unusually high count of errors. The 25-error month (April 2018) occurred seven months following the month of implementation; the 7-error month (March 2018) occurred six months after implementation. The highest error count in a single month among the other care levels was 6. Assuming the data sample was not recorded in error by the participating RACF organisation, something out of the ordinary distinctly occurred in the Intellectual Disability group in April 2018 considering the incident count of 25 is a distinct outlier both within its own group and among all care levels involved in the study. Of these 25 errors, 3 were classed as 'Not Given' errors, while the remaining 22 were all listed as 'Other'. Problematically, as the details of these errors were not provided beyond the error type as categorised by the participating RACF organisation; this is especially questionable considering 22 of the errors were categorised as 'Other' errors, so the error class itself is ambiguous and provides comparatively little detail about the nature of the errors. As a result, it is exceedingly difficult to interpret what occurred and whether or not System *X* had an impact on the high number. Furthermore, it is uncertain if the 'Other' errors were related to one another or independent of each other as the 'Other' category

encompasses all medication administration errors which do not fit into the established error types. With this in mind, it is reasonable to analyse the data without the outlying data sample.

As noted in Chapter Two, Intellectual Disability care in this case is considered to be a high level of care and can be more volatile in changes to medication management than its aged care counterparts. Of the care levels involved in this study, the Intellectual Disability had the highest average number of medications prescribed per patient in the post-implementation period, with 10.98 medications charted per patient compared to 10 for Rest Home level patients and 9.25 for Dementia level patients. The pre-implementation number of medications is not known.

The second part of the research involved gauging whether or not any medication administration error classifications were reduced or eliminated with the introduction of System *X*. The error types measured included:

- Wrong resident (medication given to or attempted to be given to the wrong person)
- Wrong dose (administration of the incorrect dose of medication)
- Wrong time (administration of medication at the incorrect time)
- Wrong day (administration of medication on the incorrect day)
- Pill found on floor (medication found on floor of patient's room following administration)
- Not given (omitted dose of medication)
- Medication – reaction (reaction to administered dose medication)
- Other (any medication administration-related incident which does not fall into the above categories)

The error counts were analysed based on the medication administration error category they were classed into by the participating RACF organisation. Across all care levels, all medication administration error types reduced in count apart from the 'Med Reaction' and 'Other' categories. The Mann-Whitney *U* test indicated no significant differences between the pre- and post-implementation periods apart from the 'Wrong Time' error, which demonstrated a significant reduction with a *p*-value of 0.03. Of the error types which increased in number following System *X* implementation, the 'Med Reaction' category, however, had an especially low number of samples, with only one occurrence of the error overall, taking place in the post-implementation period. The 'Other' category is undefined in its parameters, encompassing all medication administration errors which did not fit the other listed categories.

While the results were predominantly not statistically significant, the overall drop in medication administration errors occurring is promising, especially considering the short period of time evaluated.

Despite the number of facilities involved in the study and the range of time within which errors were collected, the dataset is notably small. While this is a relatively good thing (considering it means few errors are occurring at the involved RACF organisation), this also provides limited data to work with in the study. As System *X* has only been in use at the participating organisation since mid-2017, less than two years of post-implementation data could be used. This is a consideration for further research.

Furthermore, only a two-month post-implementation adjustment period was used in this study, deviating from the usual three months (E. Munyisia & Yu, 2016). The month of implementation was excluded in addition to the two months following implementation. The two-month period was used instead of the three-month period as most studies using the three-month post-implementation period involved more than just eMAR adoption, such as concurrent electronic prescribing implementation (Fuller et al., 2018; Vicente Oliveros et al., 2017). However, Munyisia *et al. s*uggest that even three months is not sufficient in terms of care staff becoming acclimated to eMAR systems, finding that care staff's time spent on documentation compared to direct care increases in the first 12 months and does not return to pre-implementation levels until 23 months after implementation (E. Munyisia & Yu, 2016). Post-implementation medication administration errors may then still be affected across research using the three-month post-implementation period as care staff may not have fully adjusted to eMAR use until at least 23 months following implementation (E. Munyisia & Yu, 2016).

5.3.1. The Aged Care Cohort

When the Intellectual Disability care data were excluded from the regression analysis of the error rates, the MAE rate decreased significantly following System *X* implementation. In the primary analysis, this was the only significant result. However, within the context of this research, this result is perhaps the most pertinent as System *X* was designed for use in aged residential care, and it is therefore promising to see a significant downward trend in MAE rate in the aged care-related data. The Intellectual Disability data were included due to its similarities to aged residential care in terms of medication management practice and regulations, but this does not negate the

difference in clinical practice. The care considered high-level with high dependency residents, like some aged care settings such as Dementia, but the medications and residents' behaviour involved in Intellectual Disability settings can differ greatly from those in their aged care counterparts. Due to increased complexity of care, medication changes in high-level care settings like Intellectual Disability may occur more often and more drastically than in the low-level care settings like Rest Home care, which consist of supportive care rather than 24-hour nursing care (Burrow et al., 2017); this can add pressure to the health professionals maintaining the medication regimes74.

System *X* is used predominantly in aged care specific care settings, with only 2.6% of facilities currently using the system dedicated to care unrelated to age. However, further research could be done in the area of intellectual disability to improve System *X*'s efficacy in other sectors of healthcare.

5.3.2. The Wrong Time Error

The 'Wrong Time' error type change before and after System *X* implementation produced the other statistically significant result in the study. A way to control for false discovery in this case would be to go back and look at the raw data to see what occurred. Notable in this case is that the error type is relatively uncommon across the dataset, occurring only 15 times in total (13 occurrences prior to System *X* implementation and 2 after). This is small when compared to the total number of other error types, such as the 'Not Given' errors with 91 occurrences or the 'Other' errors with 79. Thus, there is a reasonable possibility that the statistically significant result happened by chance.

However, the 'Wrong Time' error appears to be the error type which consistently reduces with eMAR implementation (Kruse et al., 2017; Qian et al., 2015; Vicente Oliveros et al., 2017). Oliveros *et al*. noted a significant decrease in 'Wrong Time' errors following eMAR implementation during their evaluation at a university hospital (Vicente Oliveros et al., 2017). Like the current study, Oliveros *et al*. found all error types decreased following eMAR implementation, but the 'Wrong Time' error type was the only one measured which had a statistically significant reduction (Vicente Oliveros et al., 2017). Kruse *et al.* further noted an improvement in timely medication management following EHR adoption (Kruse et al., 2017). Qian *et al.* found the eMAR system implemented in their study alleviated numerous medication administration errors related to timing, including 'Wrong Day' errors (Qian et al., 2015). While the decrease of 'Wrong Day' errors was not significant in this study, the number of errors did reduce (in raw count) following

System *X* implementation. However, the 'Wrong Day' error type was also uncommon in the dataset, with the total number of samples amounting to 4 across the entirety of the duration of the study, with 3 occurring prior to System *X* implementation and 1 occurring after implementation. With such a minuscule number of 'Wrong Day' samples, it is clear that 'Wrong Day' errors did not commonly occur prior to EMM implementation contributing to this study's result being insignificant despite the 66.66% reduction.

5.3.3. Medication Administration Error Reporting Improvements

Improved reporting was noted by the primary investigator to be a benefit of System *X*'s implementation into RACFs, especially in the design of the research. In considering methods for statistical analysis, it became quickly evident that the total number of opportunities for medication administration errors would be beneficial; however, while the primary investigator was able to collect this information from System *X,* it proved difficult to do so for the pre-implementation stage, in part due to limited time and proneness to error and therefore inaccurate information. It could therefore be stated that acquiring medication management data from an EMM solution like System *X* is less time-consuming and likely more accurate than similar data acquisition from a paper-based medication management system.

It should also be considered that the more efficient reporting and tracking of medication administration information may increase the visibility of errors, thereby inflating the number of errors post-intervention when compared to the pre-intervention period. Furthermore, systems like System *X* provide better oversight for corporate or senior staff by allowing them to generate medicine usage and administration reports and review live missed medications, increasing capacity for finding medication administration errors. In this sense, it may appear more errors occur following System *X* implementation due to the potential for limited visibility and under-reporting in the paper-based system.

Another benefit associated with more efficient reporting in System *X* points to deprescribing and other methods of reducing the negative impacts of polypharmacy. Though not a benefit entirely specific to medication administration errors, the comparative ease of extracting information about medicine use in RACFs has the potential to assist prescribers, RNs, and clinical specialists with mapping prescribing practice and usage of PRN medications, which could be

beneficial in taking steps toward deprescribing and reducing polypharmacy prevalence in aged care.

5.4. Implications in Improving Medication Risk Management

Certain aspects of aged residential care in New Zealand were note taken into consideration in the present study. Following evaluation of medication administration errors occurring before and after System *X* implementation at an RACF organisation, it is worth considering other factors which may affect the workflow of the system and potentially impact medication safety as a result.

5.4.1. Respite Care

Respite care encompasses a variety of services provided temporarily to a person (M. Willoughby et al., 2018). With elderly people remaining in their own homes longer rather than transitioning permanently into RACFs, demand for respite care is high (M. Willoughby et al., 2018). Residential respite care refers to a patient residing at an RACF on a temporary rather than permanent basis based on either an emergency or a planned admission (M. Willoughby et al., 2018). Respite stays are generally short, ranging from one day to six weeks (M. Willoughby et al., 2018). Respite patients at RACFs can further complicate medication management by presenting numerous issues for care staff, including lack of familiarity with the patient, potentially his or her doctor, and his or her chart (M. Willoughby et al., 2018; M. K. Willoughby, Chebi, Ferrah, Bugeja, Winbolt, & Ibrahim, 2017). The transition of care, as in the handover of respite patients' medical information upon admission and discharge is hazardous with regard to medication errors (M. Willoughby et al., 2018).

5.4.2. Polypharmacy

More than one in six older people (the population of people over 65) in New Zealand are living with three or more chronic conditions (Frey et al., 2015; Heppenstall et al., 2016). Chronic conditions are often treated with medication, suggesting the more chronic conditions one is diagnosed with, the more medications one is likely to be taking (Rieckert et al., 2018). Older people in RACFs are typically prescribed more medications than their home-living counterparts, with an average of 10 medications prescribed for every RACF resident (Qian et al., 2015; Wallis, 2015). Polypharmacy, or the concurrent use of multiple medications, is already highly prevalent in elder

care and is increasing, as is the demand for higher-level care, like hospital and dementia services (Fleming, 2010; Wallis, 2015). Furthermore, older people typically are more susceptible to ADEs when they occur and generally have poorer outcomes as a result (Frazier, 2005; Heppenstall et al., 2016). Polypharmacy in aged care is directly pertinent when considering the impact of medication errors as polypharmacy increases the likelihood of medication errors and resultant adverse drug events (Gurwitz et al., 2005; Mahmood, Chaudhury, Gaumont, & Rust, 2012; Nguyen, Fouts, Kotabe, & Lo, 2006).

5.4.3. Transition of Care

Transition of care is an additional source of medication error for patients (Bonaudo et al., 2018; Farris et al., 2017; Fitzgibbon, Lorenz, & Lach, 2013; Wheeler, Scahill, Hopcroft, & Stapleton, 2018). Transition of care refers to a patient's transfer between sources of care, such as moving from an RACF to an acute hospital or vice versa (Fitzgibbon et al., 2013; Wheeler et al., 2018). During a patient's move between hospital and RACFs, the patient's medical records must also be transferred, and information is often entered into the receiving facility's systems as part of a medication reconciliation, or "the process of reviewing a patient's medication history, resolving discrepancies and identifying the appropriate list of medications for the patient" (Hron et al., 2015; Wheeler et al., 2018). Data reconciliation into different information systems can result in medication discrepancies, or "unexplained differences among documented regimens across different sites of care" (Tjia et al., 2009). Over half of medication errors are caused by medication discrepancies, and up to a third of medication discrepancies can cause harm to a patient (Cornish et al., 2005; Mekonnen, Abebe, McLachlan, & Brien, 2016; Rozich et al., 2004). Medication discrepancies and miscommunication are common even in interdepartmental transfers within the same facility, which can contribute to serious medication errors and potential harm for patients (Cornish et al., 2005; Hron et al., 2015; Mekonnen et al., 2016; Tjia et al., 2009; Wheeler et al., 2018).

Transition of care is of particular concern for elderly patients as they may not actively participate in the decision-making process or medication reconciliation of their medications (Hughes & Goldie, 2009). This is especially the case for RACF patients as they have less agency around their medications than their independent counterparts and may not be aware of what they are being administered, especially in levels of care with high dependency patients, like dementia

(Farris et al., 2017; Hughes & Goldie, 2009). Furthermore, RACF patients are more likely to be admitted to hospital when visiting emergency departments and generally have more complicated care regimens than those who do not reside in RACFs, rendering care coordination even more difficult (Wang, Shah, Allman, & Kilgore, 2011).

The introduction of EMM systems does not diminish the necessity of medication reconciliation following transition of care (Health Quality and Safety Commission, 2012a). Medication reconciliation has been proven to significantly reduce the rate of medication administration errors due to poor documentation and is expected to remain a part of the RACF admission process regardless of whether EMM or paper-based systems are in use (Health Quality and Safety Commission, 2012a; WHO Collaborating Centre for Patient Safety Solutions, 2007). With this in mind, one could expect that the medication reconciliation process would improve with EMM solution adoption as a result of improved legibility (R. A. Elliott, Lee, & Hussainy, 2016; Mekonnen et al., 2016; Zadvinskis et al., 2013). However, process changes take adjustment, and HIT has impacted other areas of patient care in addition to medication management, in which case RACF staff members may have to adjust to multiple new programs simultaneously (Cresswell, Bates, & Sheikh, 2013).

Moreover, System *X* and other RACF EMM systems in New Zealand are not end-to-end solutions; various steps of the medication management process therefore continue to occur outside of the EMM system, which can result in double-handling of information and the potential for resultant errors (A. Tariq et al., 2014). For example, the prescription process takes place entirely outside System *X*, meaning prescriptions for charted medicines must be generated separately to the chart. While integration with a New Zealand dispensing software generates medication charts automatically from dose pack information, improving on the paper-based model, discrepancies can still occur between the medication chart and the corresponding prescriptions. Furthermore, if the pharmacy is for any reason unable to export the chart from their dispensary software, a patient's GP must input the chart into System *X* manually, further increasing the risk for error by double-handling the information (Kruse et al., 2017).

Transition of care also presents a problem by increasing the possibility of a temporary hybrid system of paper charts and eMARs in System *X.* When an RACF patient transfers between two facilities using System *X,* the chart can be moved from facility to facility within System *X,* carrying over both charted medications and other documented information like allergies, medical

conditions, and photos. To enforce the medication reconciliation process, when transfer between System *X* facilities occurs, all medications revert to 'Requiring Approval' status, meaning a prescriber must review the chart and approve all medications prior to any medications being administered using the chart. However, if a patient has transferred from the hospital or from an RACF using a paper-based system or the competing EMM product, there is no seamless transfer of medication information in System *X*; in such cases, the chart must be exported from the pharmacy's dispensing software or manually created by the GP, which can take time. Until the patient's chart can be created and updated in System *X,* the patient's medication information remains on a temporary paper chart, meaning the RACF care staff are using both paper and electronic systems concomitantly. This increases the likelihood of medication administration errors as care staff must remember there are paper charts to address in addition to those in their usual system (Qian et al., 2015).

5.5. Expansion of Electronic Medication Management to Other Sectors

System *X*'s design for residential care and that of similar EMM solutions could potentially be adapted for use in other areas involving medication management in New Zealand's health care sector. While certain aspects of System *X* and other systems like it are geared predominantly toward patients with high dependency on their caretakers, RNs and HCAs care for patients in the community as well, usually patients with more agency. However, this does not negate the medical responsibilities of health professionals like RNs. Some methods of community care may also present higher risk of medication-related harm for older people in care (R. A. Elliott, Lee, Beanland, Vakil, & Goeman, 2016).

5.5.1. District Nursing

District nursing refers to nursing in the home with the aim of enabling "people to remain in their home during health challenges that would otherwise require hospitalisation" (Ministry of Health, 2011a). Medication management is a primary component of community nursing, and patients are often referred to district nursing services for assistance with high risk medication management (R. A. Elliott, Lee, Beanland, et al., 2016; McGraw & Topping, 2011; Ministry of Health, 2011b). With the rapidly ageing population and the growing number of comorbidities, dependency on health care services is set to increase, especially hospital-based services (Ministry of Health, 2011a); this can prove costly for New Zealand's health system District nursing services

can help alleviate some of this burden as well as facilitate patients remaining more independent in their own homes (Ministry of Health, 2011a).

Like residential care, district nursing patients have multiple health professionals involved in their care: the prescribers designing their treatment plan, the pharmacists dispensing prescribed medications, and the RNs administering medications to the patients (Ministry of Health, 2019a). Unlike residential care, however, patients are responsible for seeing the doctor and collecting their own prescriptions from the pharmacy (Ministry of Health, 2019a); district nurses resultantly have less direct contact with the other health professionals involved in their patients' care compared to their RACF counterparts (R. A. Elliott, Lee, Beanland, et al., 2016). However, district nurses are responsible for ensuring a continuity of service for the patient, including communicating any risks to the prescriber, necessitating effective communication links between district nurses and other health professionals involved in a community patient's care (Home and Community Health Association, 2017).

District nurses are not necessarily responsible for giving their patients all their medications, rather just the medicines specified by the prescriber; these medications can be anything the prescriber considers the patient to require support with, ranging from regular eye drops to injections to titrating medicines such as warfarin. Similar to RACF RNs, district nurses use medicine charts written by prescribers as the authority to administer the medications (Ministry of Health, 2019a). This is especially important in district nursing as the medications they are generally tasked with administering are often not packed in dose packs (Ministry of Health, 2019a). However, these charts do not necessarily have the same formal 90-day review period that RACF charts do, though the medications are expected to be reviewed at least every three months depending on the severity or risk of the medications prescribed (Home and Community Health Association, 2017). Furthermore, the doctor does not necessarily go to the patient's home to review their treatment plans (Ministry of Health, 2019a); as a result, when changes in a patient's medication management occur, a district nurse must source a newly written chart from the doctor prior to administering any newly charted or changed medications (Ministry of Health, 2019a). The charts can become messy with numerous changes, and the process can quickly become error-prone with written charts faxed between the prescriber's practice and the district nurse (Ministry of Health, 2011a). Furthermore, it can become excessively time-consuming if the district nurse has to physically go to the prescriber's practice to pick up a chart (Ministry of Health, 2019a).

Combined, these factors put district nursing at high risk of medication-related error and potential harm (R. A. Elliott, Lee, Beanland, et al., 2016).

EMM solutions like System *X* provide a singular point of truth for medication charting and administration, which could improve documentation in district nursing as they have in RACF settings (Qian et al., 2015). However, the major foreseeable benefit to EMM adoption in district nursing would be the time (and thereby financial) savings related to medication changes, as changes are cloud-based (Pearce, 2018). For example, if a doctor makes a change to a chart in an EMM system, the district nurse sees the change right away and could therefore administer based on a legible chart without having to ensure he or she has the most current copy of it. EMM solutions like System *X* have the potential to improve communication between health professionals involved in community patients' care as well as save time for both prescribers and district nursing staff (Pearce, 2018).

5.5.2. Home Care/Support

Home care or support does not always necessitate nursing care (Ministry of Health, 2019a). Depending on the complexity of care for the patient, some support can be provided by home support workers (HSWs), HCAs' community care counterparts (Ministry of Health, 2019a). HSWs must pass an annual medication competency and work under the delegation of an RN (Home and Community Health Association, 2017); however, while HSWs often receive training specific to their role within an organisation, this is not recognized as formal or specialised nursing training or knowledge, and HSWs are not registered with any government-affiliated nursing agencies (Home and Community Health Association, 2017; Ministry of Health, 2019a). In the event an HSW is expected to administer a high risk medication, such as cytotoxic medications or warfarin, they must first undergo training specific to high risk medication administration and must be signed off by the relevant organization prior to administering high risk medications to patients (Home and Community Health Association, 2017).

As in the residential care setting, district nurses and HSWs must document medication administrations at the time of the administration (Home and Community Health Association, 2017; Ministry of Health, 2019a). However, there are different levels of medication support within community care based on the needs of the individual patients: independent, prompting, and staff administration (Home and Community Health Association, 2017). Staff administration support

refers to manual assistance with medications due to physical, cognitive, or behavioural impairment – this aligns with residential setting practice, in which medications are administered based on an up-to-date chart provided by a prescriber and the administrations are acknowledged in a timely manner (at the time of administration) on a medication administration record (Home and Community Health Association, 2017). In this context, EMM benefits are relatively easy to visualise given the similarities in practice with RACF medication administration; benefits are possibly more relevant in the community medication administration space based on potential time savings and process efficiencies, as noted in Section 6 of this chapter. However, there are two other categories of medication management support in New Zealand community care: independent and prompting (Home and Community Health Association, 2017). Independent medication support is effectively a lack thereof from a community care perspective; following an assessment by a health professional, the patient is deemed safe to administer his or her own medication(s) or that they have a reliable friend or family member to assist them in the process (Home and Community Health Association, 2017). Apart from the assessment to confirm a patient's independent ability to adhere to their medications, a district nurse or HSW is not involved in the medication management of patients classed as independent (Home and Community Health Association, 2017). In these cases, HSWs are generally involved in other manners of care, such as showering, toileting, and getting dressed (Ministry of Health, 2018d). Patients in the prompting category, on the other hand, require reminders by an HSW to take their medications (Home and Community Health Association, 2017). HSWs do not have to document that medications have been taken as they are not responsible for the administration of the medicine(s). Adaptation of an existing EMM solution like System *X* presents the opportunity to enable HSWs to acknowledge that they have prompted their patients and record if they witnessed their patients taking their medications, potentially improving documentation in this area. Furthermore, this would enable corporate or management oversight and may improve insight into prompting patients' medication adherence.

5.6. Summation of the Findings

The results of this research demonstrated a significant reduction in MAE rate within the aged care specific cohort of the provided data following an EMM system's implementation. Furthermore, a statistically significant reduction was found in MAE type occurrence following System *X* implementation – 'Wrong Time' errors reduced significantly. However, while other

changes were not statistically significant, an overall downward trend in MAE rate was clear following the system's adoption into the participating organisation. This was also the case within the Dementia and Rest Home care levels individually. The remaining care level, Intellectual Disability, had an increase in medication administration errors following the system's implementation, but the errors which increased were categorised as 'Other' errors, the bulk of which occurred in a single month; it was therefore inconclusive as to whether or not System *X* had any direct influence on this sudden increase in medication errors for the Intellectual Disability RACF. The overall reduction of medication administration errors in the year following System *X* implementation across the participating RACF organisation's seven facilities (comprising nine groups of separate care levels) is promising and merits further investigation into the MAE rate reduction and the types of errors occurring.

Benefits of EMM solutions like System *X* could be extrapolated to community-based medication services, such as district nursing and home support. With the ageing population in New Zealand set to increase the need for aged residential care, concurrently, the reliance on community health services like district nursing and home support are set to increase (Ministry of Health, 2011a). Investigation into community-based medication administration error occurrence is necessary prior to EMM system adaptation and design for use in this area.

5.7. Recommendations for Further Research

There were numerous limitations to the data used in this study. No information, such as age, role, education, or experience with technology, was provided for staff members who were involved in the errors; this information is relevant and may affect the number and type of errors occurring. Furthermore, details of the incidents were not provided beyond the error type classifications given by the organisation; details of the incidents, especially 'Other' error occurrences, could indicate introduced or eliminated errors following System *X* adoption. Perhaps most critical of the study's limitations was a dearth of information pertaining to the total numbers of opportunities for error in the pre-implementation stage, as this may provide for a more accurate statistical method for analysis. Near-miss incidents were also not included.

As a result of limitations in data and scope, many aspects of this study are therefore amenable to further research. In terms of continuing analysis of medication administration error counts, it would be crucial to expand the number of participating facilities (and, where possible,

care levels) around New Zealand as much as possible; the present study was restricted to an organisation within an urban centre of New Zealand, the name of which is not revealed for the organisation's anonymity. The relative reduction in error rate predicted by this research's analysis is encouraging and may prove statistically significant with a larger dataset. The expansion of pre- and post-intervention periods would also prove beneficial in that it could accommodate a more accurate adjustment period (Munyisia, Yu, & Hailey, 2013).

Usability and ease of workflow was also unaccounted for in this study, which may be directly related to medication administration error occurrence. A qualitative study investigating acceptance and perspectives of System *X* users may provide insight in terms of whether or not System *X* is perceived to reduce errors as well as how updates and new features in the evolving system may have assisted with medication administration error reduction. Furthermore, research into how System *X* users are using the system in practice may shed light on workarounds or failures to follow the system's procedures.

Lastly, it would be pertinent to examine medication administration errors in trial use of System *X* in other medication management settings of the health system such as district nursing or home support services. This is also a prime opportunity to examine medication administration error in district nursing services, of which there is a paucity, prior to documented implementation of System *X* or a similar EMM product (R. A. Elliott, Lee, Beanland, et al., 2016; McGraw & Topping, 2011).

5.8. Conflict of Interest

The author is currently employed full-time by the company which owns System *X* and received salary support during the project for her work in the company. The author was not provided any extra funding, financial support, or incentive by the company for this project, and salary support was provided only for her day-to-day occupation.

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APPENDICES

Appendix 1 – Ethics application

Ref: HEC Application 2018/80/LR - Cauble-Chantrenne

Human Ethics
Sent: Monday, October 01, 2018 11:15 AM
To: Alexandra Cauble-Chantrenne
Cc: Arindam Basu

Dear Alexandra,

Thank you for your low-risk application to the Human Ethics Committee.

The Chair has reviewed your application and we can confirm that no ethical approval is required for this project as the data you will be using is secondary and anonymous.

Kind regards,

Rebecca Robinson
Ethics Coordinator and Erskine Programme Administrator
Level 5 South, Matariki Building
University of Canterbury ~ Te Whare Wānanga o Waitaha
Private Bag 4800, Christchurch 8140, New Zealand
Ph: +64 3 369 4588, Ext: 94588
Email: human-ethics@canterbury.ac.nz
Ethics hours of work: Mon 2.30-5pm, Tues 8.30-11am, Wed 8.30-5pm, Thu 2.30-5pm, Fri 8.30-5pm

Appendix 2 – R statistical package 'AER'

AER – Applied Econometrics with R

Functions, data sets, examples, demos, and vignettes for the book: Christian Kleiber and Achim Zeileis (2008), Applied Econometrics with R, Springer-Verlag, New York. ISBN 978-0-387-77316-2.

Authors: Christian Kleiber [aut] and Achim Zeileis [aut, cre]

Package: AER

27 December 2018

Version 1.2-6

URL: https://CRAN.R-project.org/package=AER

Appendix 3 – R statistical package 'ggplot2'

ggplot2 – Create Elegant Data Visualisations Using the Grammar of Graphics

A system for 'declaratively' creating graphics, based on "The Grammar of Graphics". You provide the data, tell 'ggplot2' how to map variables to aesthetics, what graphical primitives to use, and it takes care of the details.

Authors: Hadley Wickham [aut, cre], Winston Chang [aut], Lionel Henry [aut], Thomas Lin Pedersen [aut], Kohske Takahashi [aut], Claus Wilke [aut], Kara Woo [aut], Hiroaki Yutani [aut], RStudio [cph]

Package: ggplot2

16 June 2016

Version 3.2.0

URL: https://CRAN.R-project.org/package=ggplot2

Appendix 4 – R statistical package 'lmtest'

lmtest – Testing Linear Regression Models

A collection of tests, data sets, and examples for diagnostic checking in linear regression models. Furthermore, some generic tools for inference in parametric models are provided.

Authors: Torsten Hothorn [aut], Achim Zeileis [aut, cre], Richard W. Farebrother [aut] (pan.f), Clint Cummins [aut] (pan.f), Giovanni Millo [ctb], David Mitchell [ctb]

Package:

30 April 2019

Version 0.9-37

URL: https://CRAN.R-project.org/package=lmtest

Appendix 5 – R code

```
require(ggplot2)
require(lmtest)
require(AER)

"
This first section is the analysis using GLM.

"
set_cap <- function(fac){
  # Function used to add a capacity for a specific facility (not in
inputted dataframe).
  # Args:
  #   fac: the facility code as a string (e.g. "D1")
  # Returns:
  #   Integer based on the capacity of the facility

  if (fac == 'D1'| fac=='D5'| fac =="I1"){
    return(40)
  } else if (fac == "D2"){
    return(27)
  } else if (fac == "D3"){
    return(14)
  } else if (fac == "D4" | fac == "D6"){
    return(41)
  } else if (fac=="R1"){
    return(54)
  } else if (fac == "R2"){
    return(52)
  } else {
    return(NaN)
  }
}

error.df <-    read.csv("error_data.csv")
# Just so I can analyse both with and without the outlier, I created
two separate dataframes.
df.with_outlier <- error.df
df.without_outlier <- error.df[-c(289),] # row 289 is the row that is
the outlier for I1

clean_frames  <- function(df){
  # Adjusts the dataframes to add new columns required for GLM
analysis.
  # Args:
  #   df: dataframe to "clean"
  # Returns:
  #   New dataframe that has new columns for capacity and OBR x
capacity. This is then aggregated (function=sum) by
  #   the "diff" i.e. relative month to implementation.
  #   An error rate is also added based on errors/OBR x capacity) and
then adjusted per 100,000 patients.
```

```
  # Creating a column for capacity based on the facility code.
  df$capacity <- lapply(df$Fac, set_cap)

  df$sPeople <- apply(df[,c('OBR', 'capacity')],1, function(x){
    # Function to calculate OBR x capacity for each row
    # Arg:
    #   x: row in a dataframe (x[[1]] = OBR type(int), x[[2]] =
capacity type(int))
    x[[1]] * x[[2]]
  })

  # Aggregating the dataframe by the diff (i.e. month relative to
implementation) and summing both the MAE and Cap x OBR.
  # in the process
  df <- aggregate(df[,c('MAE','sPeople')], by=list(df$diff), FUN=sum)

  # Aggregating removed the title of one of the columns, so resetting
these to make sense.
  df <- setNames(df, c("diff", "MAE", "Cap X OBR"))

  # Creating a new column to assist in analysis. If it's pre-
implementation, then 0 otherwise 1.
  df$grp <- with(df, ifelse(diff<0, 0, 1))

  # Creating a new column called error_rate.
  df$error_rate <- apply(df, 1, function(x){
    # Function to calculate the "error rate" per 100,000 patients.
    # args:
    #   x: the specific dataframe row (x[[2]] = MAE type(int), x[[3]] =
"Cap x OBR")
    (x[[2]] / x[[3]]) * 100000
  })
  return(df)
}

# Now to "clean" the two frames and add the data I need to each for
analysis:
df.with_outlier.agg <- clean_frames(df.with_outlier)
df.without_outlier.agg <- clean_frames(df.without_outlier)

# I decided to write a function to make the plotting consistent.
plotting <- function(df, xaxis=c(-21, 17), yaxis=c(0, 8)){
  # Creates a ggplot for the specifed dataframe
  #
  # Args:
  #   df: the specific dataframe to plot
  #   xaxis: a list representing the xlimits wanted for the plot which
represents the relative months,
  #          must be a list of two integers. Default is -21 to 17.
  #   yaxis: as per xaxis, but to adjust ylimits.
  #          default is 0 to 8.
  # Returns:
  #     Nothing, but creates a plot with the above specifications.
```

```
  f <- ggplot(df, aes(diff,error_rate))
  f + geom_point() +
    scale_x_continuous(limits=xaxis, breaks=seq(min(df$diff),
max(df$diff), by=1)) +
    scale_y_continuous(limits=yaxis, breaks=seq(min(0), max(8),
by=0.5)) +
    geom_vline(xintercept=0) +
    geom_smooth(method= loess) +
    labs(x="Number of months relative to implementation", y="Error rate
per 100,000 patients per month")
}


# Gaussian GLM function
gauss <- function(df){
  # Runs both the GLM on the inputted dataframe as well as the Durbin-
Watson test.
  # Args:
  #   df: dataframe to analyse
  # Return:
  #   Nothing, but prints the results to console

  #1 Run the GLM model on the dataframe (arg=df) with family Gaussian.
  lm <- glm(formula=error_rate~grp, family=gaussian, data=df)

  #2 Getting the summary of the GLM model
  print(summary(lm))

  #3 Get the Durbin-watson test to check residuals for autocorrelation.
  dwtest(lm, alternative = "two.sided")

  # Getting confidence intervals on GLM result.
  confint(lm)
}

#1 Test the full dataframe.
plotting(df.with_outlier.agg)
gauss(df.with_outlier.agg)

#2 Test the data without the outlier.
plotting(df=df.without_outlier.agg, yaxis=c(0, 4)) # setting the y
limit to 4
gauss(df.without_outlier.agg)

#3 Resting Rest Home and Dementia care only.
x <- error.df[!(error.df$Care_Level == "Intellectual"),]
x.agg <- clean_frames(x)
plotting(x.agg, yaxis=c(0, 4))
gauss(x.agg)

#4 Sub analysis of 1 and 2 based on care level.
#4a - Dementia care
dementia <- subset(error.df, Care_Level == "Dementia")
dementia.agg <- clean_frames(dementia)
```

```
plotting(dementia.agg, yaxis=c(0, 5))
gauss(dementia.agg)

#4b - Rest Home care
rest_home <- subset(error.df, Care_Level=="Rest Home ")
rest_home.agg <- clean_frames(rest_home)
plotting(rest_home.agg, xaxis=c(-19, 17), yaxis=c(0, 6))
gauss(rest_home.agg)

#4c Intellectual Disability care
# i. with outlier
intellectual.outlier <- subset(error.df, Care_Level == "Intellectual")
intellectual.outlier.agg <- clean_frames(intellectual.outlier)
plotting(intellectual.outlier.agg, xaxis=c(-20, 15), yaxis=c(0, 5)) #
note +7 is at 56 so not included in the frame
gauss(intellectual.outlier.agg)

# ii. without outlier
intellectual.no_outlier <- subset(df.without_outlier, Care_Level ==
"Intellectual")
intellectual.no_outlier.agg <- clean_frames(intellectual.no_outlier)
plotting(intellectual.no_outlier.agg, xaxis=c(-20, 15), yaxis=c(0, 5))
gauss(intellectual.no_outlier.agg)


"
This second section was used to analyse the differences in MAE type
utilising count data before and after.
"
#Importing the data.
mae_data <- read.csv("MAE_Data.csv", header=T)
err_types <- read.csv("Err_Types.csv", header=T)


#Setting up the function to handle Mann-Whitney U.
compute_tests <- function(df, column){
  #Args: df = dataframe, column is the column we're doing the test on
(i.e MAE, specific error type, etc.)
  cat("Testing on the column:", column, "\n")
  m <- mean(df[,c(column)])
  v <- var(df[,c(column)])
  cat("Dispersion index for this dataset:", v/m, "\n")
  if (column == "MAE"){ # only want to calculate the Pearson
correlation and Kendall tau on whole dataset
    cat("Pearson correlation of MAE and OBR: ", cor(mae_data$MAE,
mae_data$OBR), "\n")
    cat("Kendall tau rank correlation of MAE and OBR: ",
cor(mae_data$MAE, mae_data$OBR, method="kendall"), "\n")
  }

  before_rows <- which(df$B_A == "Before")
  after_rows <- which(df$B_A == "After")
```

```
  errors_before <- df[before_rows, c(column)]  # Selecting only the
rows flagged as "before" from the designated columns
  errors_after <- df[after_rows, c(column)]    # As above line but for
after

  print(wilcox.test(errors_before, errors_after, conf.int=TRUE,
exact=FALSE)) # doing the actual Mann-Whitney U test
}

#Test 1a: All errors and care types before and after.
print("Testing all data")
compute_tests(mae_data, "MAE")

#Test 1b: Sub analysis of #1; does the care level have an effect?
for (care_type in c("Dementia", "Rest Home ", "Intellectual")){
  cat("Testing data for care type:", care_type, "\n")
  compute_tests(mae_data[which(mae_data$Care_Level == care_type),],
"MAE")
}

#Test 1c: Stratifying by error type. Column name is difference as
that's how the .csv is set out (hence column **kwarg).
for (error_type in names(err_types[c(5:12)])){
  cat("Testing for the error type:", error_type, "\n")
  compute_tests(err_types[,c("B_A", error_type)], error_type) # only
need the columns for before/after and the error type
}

#Test 2: Before and after by care level and by error type.
for (care_level in unique(err_types$Care_Level)){
  for (error_type in names(err_types[c(5:12)])){ # getting the column
headers for the different errors
    cat("~~~~~~~~~~~~~~~~~ TESTING ON", care_level,
"~~~~~~~~~~~~~~~~~", "\n")
    care_level.df <- err_types[which(err_types$Care_Level ==
care_level),]
    try(compute_tests(care_level.df, error_type)) #computing the MWU
with the specific dataframe and errors
    cat("_____________________________________________", "\n")
  }
}
```